MINING MACHINERY

AN ELEMENTARY TREATISE ON THE GENERATION, TRANSMISSION, AND UTILIZATION OF POWER FOR CANDIDATES FOR THE UNDER-MANAGER'S CERTIFICATE

BY

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AUTHOR'S PREFACE

THIS book was intended primarily for the use of those preparing for the Board of Trade examination for Second-class Certificates of Competency as Colliery Undermanagers, and the splendid reception given to it has shown that its purpose has been achieved. The present opportunity has been taken to eliminate errors in the original form of the book and to bring up to date the questions at the ends of the various chapters, so that readers may become familiar with the questions generally set by the examiner.

The study of each branch of the subject is begun by a consideration of the leading principles upon which the further treatment is founded, and representative machines and appliances are described and illustrated by suitable drawings and photographs. The uses of typical mining plant are set forth, and consideration is given to the measures which are normally taken to ensure the safety of persons engaged in handling mining machinery, or of those whose safety depends on the proper use of such plant.

The treatment of the subject of the title is tutorial and practical, and as the progress made in learning is dependent upon the acquisitiveness of the student, the author hopes that readers of the book will be induced to extend their studies by reading the papers and books of reference specified at the ends of the several chapters, and he advises them to become familiar with the machinery to which they have daily access in the pit

Success at examinations depends to a great extent on the facility with which a candidate can express his ideas in writing,

and much depends on his ability to illustrate his remarks by suitable drawings. He should, therefore, make good use of the exercise questions at the end of each chapter of the book, and to acquire facility in drawing all drawings should be made to scale until he has acquired facility in sketching.

Those who have succeeded in passing the Undermanagers' examination will still find the book helpful to them in preparing for the higher examination for the First-class Certificate.

The author desires to take this opportunity to thank all those firms that have supplied blocks or photographs for the illustration of the book, and to express his indebtedness to those who in the workshop, laboratory or mine, have helped to fashion his ideas of mining machinery and the stupendous part it plays in the development of mining methods.

The permission of the Controller of H.M. Stationery Office has been obtained to reproduce the Examination Questions included in the book.

THOMAS BRYSON.

MINING COLLEGE,
WIGAN,
1914.

EDITOR'S PREFACE

THE Mining Certificate Textbooks have been specially prepared to meet the requirements of candidates for certificates of competency as managers and under-managers of mines.

The subjects of the examinations are given in the following extracts from the syllabus issued by the Board for Mining Examinations :-

FOR FIRST-CLASS CERTIFICATES—

1. WINNING AND WORKING. Systems of laying out and working, under varying circumstances, of coal and other stratified deposits included under the Coal Mines Act—The geology of these deposits—Methods of supporting roof and sides—Boring and sinking—Blasting and general knowledge of explosives.

2. THEORY AND PRACTICE OF VENTILATION. The properties, identification, and practical estimation of gases met with in mines—Sources and effects of heat in mines—Natural ventilation, fans, and other ventilators—The distribution and control of the air underground—Construction, use, and testing of safety lamps.

3. EXPLOSIONS IN MINES, UNDERGROUND FIRES AND INUNDATIONS, THEIR CAUSES AND PREVENTION. Coal dust—Spontaneous heating—Rescue operations, apparatus, and organization—Recovery of mines after explosions, fires, and inundations.

4. MACHINERY. Winding, hauling, pumping, mechanical coal-cutting and conveyors, etc.—Methods of transmission of power—Strength of materials.

5. SURVEYING, LEVELLING, AND DRAWING. Determination of magnetic declination—Loose and fast needle dialling—Calculation of areas and volumes—Contour lines and levelling—Traversing with the theodolite underground and on the surface—Connecting of surface and underground surveys—Triangulation—Mine plans and sections—The use, care, and testing of instruments.

N.B.—Each candidate must produce a plan of a mine survey and a section prepared from an underground levelling made and drawn by himself, with the original plottings, and the notes from which the plottings have been made, and the work must be certified by him as having been carried out by himself. The plan and section prepared from an underground levelling must have been made and drawn not more than twelve months before the date of the examination.

6. GENERAL MANAGEMENT AND MINING LEGISLATION. Organization and surface arrangements under varying circumstances—Mines Acts—General and special regulations and orders, and other legislation.

In addition to the written examination, there will be a *viva voce* examination.

FOR SECOND-CLASS CERTIFICATES—

The questions set in the respective papers for Second-class Certificates will be of a nature suitable for practical working miners.

1. Systems of laying out and working, under varying circumstances, of coal and other stratified deposits included under the Coal Mines Act—Methods of supporting roofs and sides—Boring against old workings—Shot firing.

2. Ventilation, the properties, identification, and practical estimation of gases met with in mines—Natural ventilation, fans and other ventilators—The distribution and control of the air underground—Construction, use, and testing of safety lamps.

3. Explosions in mines, underground fires, and inundations, their causes and prevention—Coal dust—Spontaneous heating—Rescue operations, apparatus, and organization.

4. Machinery and plant in common use in a colliery, including the use of electricity, and with special reference to safety.

5. Arithmetic (simple rules)—Elementary surveying and levelling.

6. Mines Act—General and special regulations and orders—Writing of reports.

In addition to the written examination, there will be a *viva voce* examination.

The first set of textbooks in the series covers the scope of the examination for second-class certificates, but in the case of two of the subjects, namely, *Mining Law and Management* and *Explosions in Mines*, it has been considered advisable to embrace the scope of both the first and the second-class examinations in one volume devoted to each subject.

Prior to the establishment of the Board for Mining Examinations under the Coal Mines Act, 1911, it would have been impracticable to have prepared suitable textbooks to deal separately with each subject, on account of the lack of uniformity that existed in the matter of standards of examination ruling in the various coalfields where the examinations were held. The establishment of one governing body to control and arrange examinations has resulted in standardization, and, incidentally, a general raising of the standard of qualifications.

Several years' experience under the existing system has enabled mining teachers and lecturers to form sound plans for the training of candidates, but however efficient a teacher may be, the student's progress depends on his application to

private study It is hoped that the present series of text-books will be found of especial value to students preparing for examinations and to mining students generally

The following books form the first series

- *Mining Machinery* by T Bryson A R T C M I Min E M I M S
- *Arithmetic and Surveying* by R M Evans B Sc F G S M I Min E
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- *Mining Law and Mine Management* by Alexander Watson A.R S M
- *Colliery Explosions and Recovery Work* by J W Whitaker Ph D, B Sc F I C M I Min E

The publishers have been fortunate in securing the services of authors who have had extensive experience in training and preparing students for mining examinations and who have otherwise distinguished themselves by their contributions to mining literature In this series of textbooks the subjects have been treated by the respective authors in a manner "suitable for practical working miners"

As the authors have aimed to meet the requirements of candidates for certificates, the keynote has necessarily been "Safety First," since in every mining operation safety precautions must be uppermost in the minds of officials and miners The same policy governs the mining examinations.

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CHAPTER I

HEAT AND STEAM

Water. Water is a chemical compound of hydrogen and oxygen, which may exist in the solid state as ice, in the liquid state as water, and in the vaporous condition, in which it is called steam. If the vapour be raised to a higher temperature than that at which it was formed, its behaviour resembles that of a perfect gas, and the resemblance becomes closer the higher the temperature, until the temperature is reached at which the constituent gases are dissociated. Water is caused to pass through the various changes indicated by the application of heat, but the order may be reversed by the abstraction of heat from the constituent gases, initially at a high temperature, from the vapour, and; finally, from the water itself.

Sensible Heat. When the application of heat to a substance causes the temperature of the substance to rise, the heat so applied is called *sensible heat*, for the change in the physical condition of the substance may be rendered evident by a thermometer. It is customary to reckon the sensible heat of water from 32° F., thus the sensible heat of water at 212° F. is $212 - 32 = 180$, meaning that 180 British Thermal Units of heat must be applied to 1 lb. of water in order to raise the temperature of the water from 32° to 212° F. The amount of heat which must be imparted to a certain mass of a substance, having a weight ω lb., to raise its temperature from $t_1°$ to $t_2°$ F., the specific heat of the substance being δ, is expressed by $h = \delta(t_2 - t_1)\,\omega$ in B.Th.U., but as the specific heat of water may, for ordinary calculations, be assumed to have the constant value of 1, the sensible heat imparted to ω lb. of water in raising its temperature from $t_1°$ to $t_2°$ F., is generally expressed as $h = \omega(t_2 - t_1)$ B.Th.U.

Latent Heat. Heat imparted to a substance to change the state of the substance without changing its temperature is said to be *latent heat.* Calorimetric determinations show that the latent heat of ice is 144 B.Th.U. per lb., and that the latent heat of steam at atmospheric pressure is 966 B.Th.U. per lb. Regnault found that the latent heat of steam varied with the temperature of evaporation; further, that the latent heat and the temperature were connected by the simple formula: $l = 966 - 0{\cdot}7\ (t^\circ \text{ F.} - 212^\circ)$, and we see that this takes the final form of $l = 1114 - 0{\cdot}7t^\circ$ F.

Total Heat in Steam. The *total heat* in 1 lb of steam at any temperature t° F., from water at 32° F., is given by the expression: $H = (t^\circ - 32) + (1114 - 0{\cdot}7t)$, the first term of the expression representing the sensible heat, and the second the latent heat. The temperature of evaporation varies with the pressure of the steam, and as steam tables have been compiled, the various properties of steam may be studied by reference to those tables, but as the reader may be interested in the properties of steam at a pressure which is not given in the tables, it becomes necessary to determine the several

TABLE I

PROPERTIES OF SATURATED STEAM

Absolute pressure in lb per in.	t F	h	l	H	Volume in cub ft. per lb of steam
2	126·3	94·4	1026	1120·4	173·2
4	153·1	121·4	1007	1128·6	89·8
6	170·1	138·6	995·2	1133·8	61·1
8	182·9	151·5	986·2	1137·7	46·6
10	193·2	161·9	979·0	1140·9	37·8
15	213·0	181·9	965·0	1146·9	25·9
20	227·9	197·0	954·4	1151·4	19·7
40	267·1	236·9	926·5	1163·4	10·3
70	302·7	273·4	900·9	1174·3	6·1
100	327·6	298·9	882·9	1181·8	4·4
130	347·1	319·0	868·7	1187·8	3·4
160	363·3	335·9	856·9	1192·7	2·8
190	377·3	350·4	846·6	1197·0	2·4
200	381·6	354·9	843·4	1198·3	2·3

properties associated with the pressure by the process of interpolation. Table I gives the principal properties of saturated steam at pressures from 2 to 200 lb. per sq. in. absolute, and if corresponding values of temperature ($t°$ F.), latent heat (l), total heat (H), and specific volume (V) be plotted as ordinates on a base of pressures, the properties of saturated steam at any absolute pressure other than those given in the table may be found by observing the values of the ordinate which passes through the given pressure and intersects the curves of temperature, latent heat, total heat, and specific volume.

Example 1. Calculate the sensible, latent, and total heat in 1 lb. of steam at 327·6° F.

Solution.

$$h = t° - 32° = 327{\cdot}6 - 32 = 295{\cdot}6 \text{ B.Th.U.}$$
$$l = 1114 - 0{\cdot}7t° = 1114 - 0{\cdot}7 \times 327{\cdot}6 = 884{\cdot}7 \text{ B.Th.U.}$$
$$H = 295{\cdot}6 + 884{\cdot}7 = 1180{\cdot}3 \text{ B.Th.U.}$$

Example 2. What weight of coal having a calorific value of 11,500 B.Th.U. per pound would be required to raise the temperature of 2000 lb. of water at 32° F. to 381·6° F., and evaporate it at the latter temperature, assuming that the efficiency of the boiler is 0·5?

Solution. The total heat in 2,000 lb. of steam at 381·6° F. = 2000 (381·6 − 32) + 1114 − 0·7 × 381·6) = 2000 × 1196·48 = 2,393,800 B.Th.U., but as the efficiency of the boiler is 0·5, the heat required is equal to 2 × 2,393,800 = 4,787,600 B.Th.U., therefore the weight of coal required = 4,787,600 ÷ 11,500 = 416·3 lb.

Example 3. Water is fed into a boiler at 63° F. and is heated to 327·6° F., at which temperature steam is generated at a pressure of 100 lb. per sq. in., absolute. Calculate the heat imparted to each pound of water.

Solution. $H = (327{\cdot}6° - 63°) + 1114 - 0{\cdot}7 \times 327{\cdot}6$
$= 264{\cdot}6 + 884{\cdot}68 = 1149{\cdot}28$ B.Th.U.

Example 4. Water is fed into a boiler at 130° F. and is evaporated to dry saturated steam at 366° F. The weight of feed-water used per hour is 4000 lb., and the weight of coal burned in the same period of time is 600 lb. The calorific value of the coal is 12,000 B.Th.U. per pound. Calculate the efficiency of the boiler.

Solution.

$$\text{Efficiency of boiler} = \frac{\text{Heat given to water}}{\text{Heat supplied in coal}}$$

$$= \frac{4000\ [(366^\circ - 130^\circ) + 1114 - 0{\cdot}7 \times 366]}{600 \times 12{,}000}$$

$$= \frac{4000 \times 1093{\cdot}8}{600 \times 12{,}000} = 0{\cdot}607 \text{ or } 60{\cdot}7 \text{ per cent.}$$

Example 5. The flue gases passing from a boiler furnace have a temperature of 520° F. and the temperature of the air entering the furnace is 55° F The amount of air used is 22 lb. per pound of coal burned. Calculate the heat lost in the furnace gases per pound of coal burned, and the percentage of heat lost if the calorific value of the coal is 12,000 B Th.U. per lb. Specific heat of furnace gases 0·26.

Solution.

Heat lost per pound of gases = change of temperature × specific heat

$$= (520^\circ - 55^\circ)\ 0{\cdot}26$$

$$= 120{\cdot}9 \text{ B Th.U.}$$

$$\text{Heat lost per pound of coal} = (520^\circ - 55^\circ)\ 0{\cdot}26 \times 22$$

$$= 2459{\cdot}8 \text{ B.Th.U.}$$

$$\text{Percentage of heat lost by gases} = \frac{2459{\cdot}8 \times 100}{12{,}000} = 20{\cdot}4$$

Mechanical Equivalent of Heat. Heat and work are mutually convertible, and *Joule's equivalent* is the rate of exchange. Dr. Joule, by his well-known stirring experiment, established the fact that, in the latitude of Manchester, 772 ft.-lb. of work had to be performed in order to raise the temperature of 1 lb. of water from 60° F. to 61° F. This is termed *the mechanical equivalent of heat* One B.Th.U. was afterwards found to be more correctly 778 ft.-lb., and that is the value now generally used.

Example 6. In generating steam for a compound engine the coal consumption is 2½ lb. per indicated horse-power per hour, the calorific value of the coal being 13,750 B.Th.U. per pound. Calculate the thermal efficiency of the plant.

Solution.

Heat given up by coal $= 2{\cdot}5 \times 13{,}750 = 34{,}375$ B.Th.U.
Mechanical equivalent of heat $= 34{,}375 \times 778 = 26{,}743{,}750$ ft.-lb.
Energy given up per minute $= 26{,}743{,}750 \div 60 = 445{,}729$ ft.-lb
Theoretical horse-power $= 445{,}729 \div 33{,}000 = 13{\cdot}51$

Thermal efficiency of plant $= \dfrac{1 \times 100}{13{\cdot}51} = 7{\cdot}4$ per cent

Example 7. A fan engine developing 120 i.h.p. required 1500 lb. of steam per hour. The temperature of the steam was 341° F., and the temperature of the exhaust steam was 170° F. Calculate the thermal efficiency of the engine.

Solution.

$$\text{Thermal efficiency} = \frac{\text{Heat equivalent of work done}}{\text{Heat supplied to engine}}$$

$$= \frac{120 \times 33{,}000 \times 60 \div 778}{1500[(341^\circ - 170^\circ) + 1114 - 0{\cdot}7 \times 341]}$$

$$= \frac{278{,}524}{1{,}570{,}050} = 0{\cdot}18 \text{ or } 18 \text{ per cent}$$

Saturated and Superheated Steam. Steam in contact with the water from which it has been formed is called *saturated steam*, and at a given pressure it can only exist at one temperature. Thus, if heat be abstracted from saturated steam some of the steam is condensed, the temperature being unaltered. If no heat were abstracted from steam after generation, there would be no spray from condensation, and the steam would be said to be *dry*, but when heat is lost by the steam to surrounding bodies condensation takes place, and the steam becomes *wet*. In a mixture of steam and spray, the proportion of dry steam to unit weight of the mixture is called the ***dryness fraction***. Under normal working conditions the dryness fraction does not usually fall much below 95 per cent, but if the ebullition of steam is violent the proportion of water carried away in the steam may exceed 5 per cent. If f be the dryness fraction of wet steam at a temperature of t° F., the total heat in 1 lb. of the steam is given by the expression—

$$H = (t^\circ - 32) + f(1114 - 0{\cdot}7t^\circ)$$

Example 8. What is the total heat in 1 lb. of wet steam at 341° F. when the dryness fraction is 0·95 ?

Solution. $H = (341 - 32) + 0·95\,(1114 - 0·7 \times 341)$
$= 309 + 0·95 \times 855·3 = 1140·5$ B.Th.U.

When heat is added to the heat of evaporation of saturated steam, the pressure being constant and the steam dry, the temperature is raised and the steam is said to be *superheated.* Superheated steam at a given pressure can exist at any temperature higher than boiling tempera ure corresponding to the pressure of the steam. The specific heat of superheated steam at constant pressure is 0·6 and at constant temperature 0·46, and the total heat required to form superheated steam at a temperature of t_2° F from water at 32° F., and saturated steam at t_1° F. is given by the expression—

Total heat in B.Th.U. $= H + 0·6\,(t_2° - t_1°)$
$= 1082·4 + 0·3t_1° + 0·6\,(t_2° - t_1°)$

[$1082·4 + 0·3t_1°$ is deducible from $(t_1° - 32)$
$+ 966 - 0·7\,(t_1° - 212)$]

Example 9. Calculate the total heat in 1 lb. of superheated steam at a pressure of 160 lb. per sq. in. absolute and a temperature of 463·3° F

Solution. On referring to Table I it will be seen that the temperature of saturated steam at the given pressure is 363·3° F., therefore the degrees of superheat added to the steam after evaporation equals $463·3 - 363·3° = 100°$. Let t_1 be the lower temperature and t_2 the higher, then the total heat in 1 lb. of superheated steam at the higher temperature

$1082·4 + 0·3t_1° + 0·6\,(t°_2 - t°_1)$
$= 1082·4 + 0·3 \times 363·3 + 0·6 \times 100$
$= 1251·39$ B.Th.U.

A like result may be got by adding the value of H corresponding to the given pressure to $0·6\,(t_2 - t_1)$, thus the required amount of heat $= 1192·7 + 0·6 \times 100 = 1252·7$ B.Th.U. Either result is acceptable.

Condensation of Steam. Heat may be abstracted from steam to condense it by admixture with water, as in a *jet condenser*, or condensation may be effected by causing steam

to pass through tubes around which cold water is caused to circulate, as in a *surface condenser.*

The amount of water required for the condensation of a certain amount of exhaust steam depends on the temperature of the steam and that of the condensing water, and it is evident that the heat gained by the water must be equal to that lost by the steam. Let $t_1°$ F. be the temperature of the exhaust steam, $t_2°$ F. the temperature of the condensing water, and $t_3°$ F. the temperature of the mixture, then for a jet condenser, the weight W of water per lb. of exhaust steam is given by—

$$W(t_3° - t_2°) = 1[(t_1° - t_3°) + 1114 - 0·7t_1]$$

Example 10. The temperature of the exhaust steam entering a jet condenser is 126° F., and that of the cooling water is 60° F., the temperature of the mixture to be maintained at 100° F. Calculate the weight of water required per pound of steam to maintain a hot-well temperature of 100° F.

Solution. $W(100 - 60) = 1[(126 - 100) + 1114 - 0·7 \times 126]$,

$$40W = 26 + 1114 - 88·2$$

$$W = 1051·8 \div 40 = 26·3 \text{ lb.}$$

In the other case of the surface condenser the steam does not mingle with the water, and therefore we may suppose that while the temperature of steam falls from t_1 F. to $t_2°$ F. in passing through a condenser, the temperature of the cooling water rises from $t_3°$ F. to $t_4°$ F. The weight of water then required to obtain a condensate at $t_2°$ F. is given by-

$$W(t_4° - t_3°) = 1[(t_1° - t_2°) + 1114 - 0·7 \times t_1°],$$

W having the same significance as in the preceding example.

Example 11. Calculate the weight of condensing water at 60° F. that is required to reduce the temperature of 1 lb. exhaust steam from 145° F. to 125° F., if the condensing water leaves the condenser at 95° F.

Solution.

Heat gained by water = heat lost by steam.

$$W(95 - 60) = 1[(145 - 125) + 1114 - 0·7 \times 145],$$

$$35W = 20 + 1114 - 101·5$$

$$W = 1032·5 \div 35 = 29·5 \text{ lb.}$$

REFERENCE BOOKS

Heat and Light, by R. W. Stewart, D.Sc.
Heat for Advanced Students, by E. Edser.
Steam and Other Engines, by Duncan.
Mechanics and Applied Heat, by Moorfield and Winstanley.

EXERCISE QUESTIONS

1. State the changes that take place in converting water to superheated steam, and distinguish latent heat from sensible heat.

2. Find the total amount of heat in 1 lb. of steam at 381·6° F. and calculate the amount of heat that must be imparted to 1 lb. of water at 100° F. to convert it to steam at 347° F.

3. Steam is generated at 328° F. from water at 120° F. by the burning of coal having a heating power of 13,000 B Th.U. per pound in a boiler having an efficiency of 0·6. What weight of coal is required per 1000 lb. of steam generated ?

4. The hot gases emerging from a boiler furnace have a temperature of 550° F., and when they have passed through an economizer the temperature is found to be 125° F. The evaporative power of the coal used is 8 lb. of water per pound of coal, and the air used for the combustion of the coal amounts to 22 lb. per pound of coal Given that the specific heat of the furnace gases is 0·26, calculate the quantity of heat imparted to the feed-water per pound of coal burned.

5. A steam engine developing 200 h.p. uses 2500 lb. of steam per hour. The pressure of the steam is 160 lb. per sq. in. absolute, and the temperature of the exhaust steam is 150° F. Calculate the thermal efficiency of the engine.

6. What do you understand by the term *dryness fraction* ? Calculate the total heat in 1 lb of wet steam at 336° F. when the dryness fraction is 0·92, and the quantity of heat that must be added to superheat the steam to a temperature of 520° F.

7. Calculate the amount of water at 45° F. required to reduce the temperature of 1 lb. of steam at 170° to the temperature of 120° F. if the condensate is to have a temperature of 80° F.

8. What is meant by saturated steam, latent heat of steam, and specific volume of steam ? How does the latent heat of steam vary with the pressure? Calculate the heat required to convert 1 lb. of water at 60° F. to steam at an absolute pressure of 100 lb. per sq. in. The temperature of saturated steam at that pressure is 328° F., and the latent heat is 892 B.Th.U. per lb.

CHAPTER II

STEAM BOILERS

Kinds of Steam Boiler. The boilers most commonly used at collieries for the supply of steam to engines are: (1) Vertical boilers; (2) Cornish boilers; (3) Lancashire boilers; (4) Water-tube boilers. In selecting a boiler plant that may be suitable for working under given côndítions, consideration must be given to—

(*a*) The capacity of the boiler to meet large intermittent demands for steam without forcing the stoking.

(*b*) The suitability of the design for safety withstanding the pressure of the steam.

(*c*) The efficiency with which the latent energy of the coal or other fuel may be converted into heat in the steam.

(*d*) The adaptability of the boiler to the use of devices by which heat is economized.

(*e*) The speed with which steam can be raised from the cold condition of the boiler.

(*f*) The accessibility of the vulnerable parts, both externally and internally.

(*g*) The space occupied by the boiler plant.

(*h*) The portability of the boiler.

Vertical Boiler. Fig. 1 is a half-sectional view of the vertical cross-tube boiler made by H. Morris, Ltd., Loughborough. It is made in sizes varying from 2 to 5 ft. in diameter and from 4 to 14 ft. in height, the evaporative capacity of the boiler varying from 106 to 1630 lb. of water per hour. Where small quantities of steam are required, as in driving a boring apparatus during prospecting work, the vertical boiler is especially suitable, for being self-contained and requiring no brickwork seating it can readily be removed from place to place. For the ground space occupied the boiler is comparatively powerful, and since the fire-grate is about as large as

the horizontal section of the boiler, steam may be rapidly generated from the cold condition.

The illustration shows the shell to consist of two rings of steel plate joined together by a single row of rivets, the furnace chamber being joined to the shell by a single row of rivets near

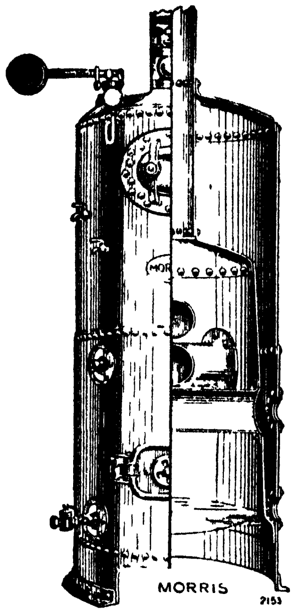


FIG. 1 MORRIS CROSS-TUBE BOILER

the base. It is also seen that small doors are provided at points opposite the ends of the cross-tubes to enable the latter to be cleaned of *scale* from time to time. The fire-grate is circular, and the uptake from the furnace passes up through the steam space and through the dished top of the boiler. The following are the fittings supplied with the boiler, viz.: a lever safety valve, a stop valve, a check valve, a set of automatically-closing water gauges, two gauge or test cocks, one blow-off cock, and a steam gauge with siphon attachment. This boiler is designed to generate steam at 100 lb. per sq. in.,

and is tested by hydraulic pressure to twice the working pressure An injector is an essential part of the equipment of a vertical boiler

Cornish Boiler Fig 2 shows a cross-section of the Cornish boiler and its seating The shell consists of rings of mild-steel plate, 4 to 6 ft diameter, joined together by single- or double-riveted lap joints, and the furnace tube, which has a diameter

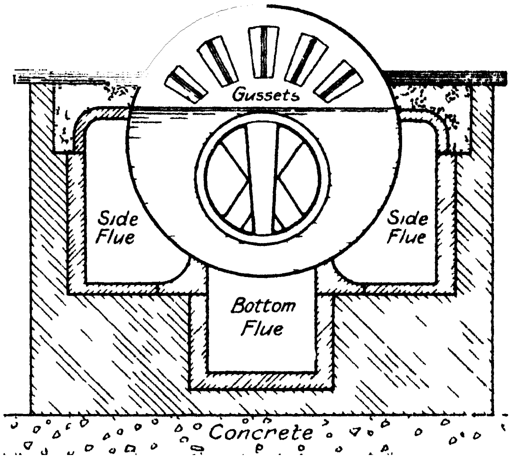


FIG 2 CROSS SECTION OF CORNISH BOILER

about 0 6 that of the shell, consists of steel tubes that are joined together by single riveted joints The illustration shows that cross-tubes are fitted to the furnace tubes, with the object of promoting circulation of the water Around the surfaces of tubes the heat from the furnace passes to the water, thus ensuring rapid generation of steam The circulation of the water takes place in the upward direction through the cross-tubes, because as the water in the tubes is heated the density is diminished, and it rises towards the top of the tube under the greater pressure of the colder water in contact with the sides and bottom of the boiler The air which passes into the furnace for the combustion of the fuel traverses the whole length of the furnace tube, and then it passes along the bottom flue from

back to front of the boiler, after which it divides and passes along the side flues, through the dampers, and into the main flue at the rear of the boiler, thence to the chimney. Table II gives some particulars of the Cornish boiler.

The figures show that the evaporative capacity of the boiler is fully twice that of the largest size of vertical boiler, but whereas the latter is portable and needs no brickwork seating, the former is less portable and must be enclosed in brickwork, in order that the flue gases may be circulated as already described. The boiler is suitable for supplying steam at moderate pressure to stationary engines of comparatively small power.

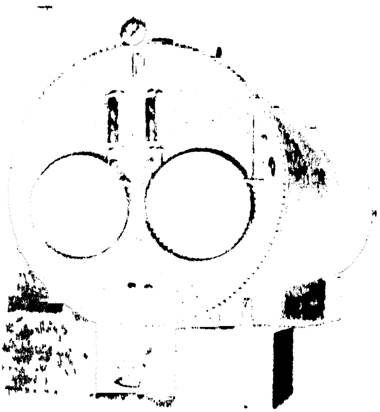


FIG 3 LANCASHIRE BOILER

Lancashire Boiler. Whereas the Cornish boiler has one furnace tube, the Lancashire boiler has two furnace tubes. Fig. 3 gives a clear idea of the construction of a Lancashire boiler having flanged end plates, and it shows that the junction of the front end plate with the shell is effected by a circumferential row of rivets

TABLE II

Dia. and length of boiler	Dia. of flues	Length of grate	Grate area.	No. of cross-tubes	Heating surface	Normal evaporation
Ft. Ft.	Ft. In.	Ft In.	Sq. ft.		Sq ft.	Lb. per hr.
4 × 11	2 0	3 3	6·5	—	130	150
5 × 19	2 8	4 0	12·0	3	310	1,750
6 × 28	3 4	6 6	21·7	5	585	3,600

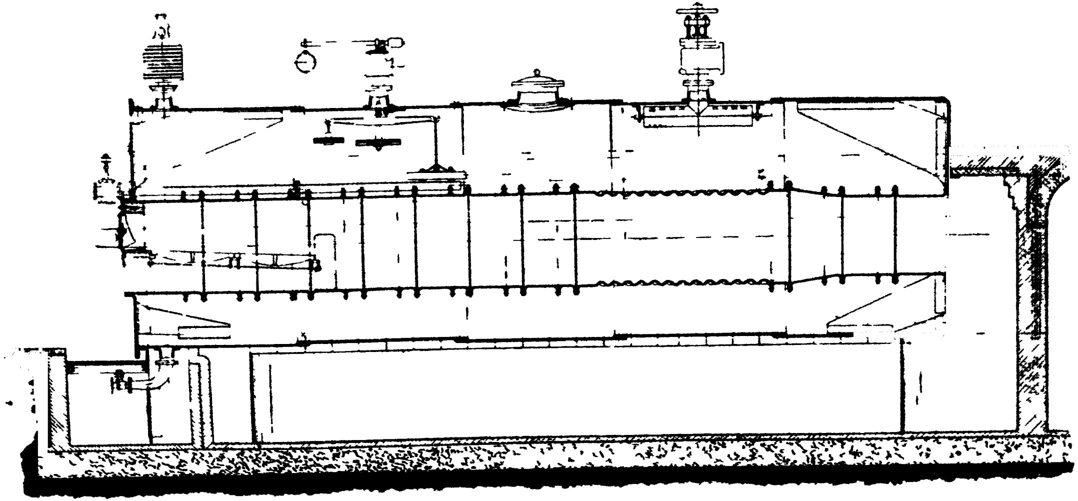


FIG 4. LANCASHIRE BOILER

and a circular angle-iron, which is riveted to the shell. The illustration also shows that the junction is strengthened by seven-gusset stays, the positions of these stays being marked by the radial rows of rivets on the end plate, and it is seen that steam and water gauges and the feed-water inlet pipe are also attached to the front plate (Section 56, Coal Mines Act). A water-level pointer is placed between the water gauges to mark the correct height of the water in the boiler under working conditions.

Fig. 4 is a longitudinal section of the Lancashire boiler and its seating, and it shows that the boiler consists of five rings, which are riveted together to form the shell. The manner in which the end plates are attached to the shell is clearly shown, and the mountings usually fitted to the boiler are shown in their respective positions on the top and bottom of the boiler. The shell varies from 6 to 9 ft. in diameter, and from 19 to 30 ft. in length. Two furnace tubes having a diameter equal to about 0·4 of the diameter of the shell pass from end to end and are riveted to the end plates. The illustration shows a portion of the furnace tubes to be corrugated, but this construction is not generally adopted when the end plates are flat, the ordinary straight tubes being preferred, but when the end plates are *dished*, and therefore more rigid than flat plates, expansion and contraction are allowed for by the insertion of a length of corrugated tube. The boiler furnace varies from 4 to 6 ft. in length, and the grate area from 18 to 45 sq. ft., the fire bars having three supports, on the dead-plate at the front of the boiler, on the flame dyke, and on a girder placed in an intermediate position. The mountings on the top of the boiler are: a dead-weight safety valve, a high-pressure and low-water safety valve, a man-hole and door, and an anti-priming pipe attached to the stop valve. A blow-off cock is mounted on the bottom of the boiler near the front plate. The evaporative capacity of the boiler varies from 2500 to 9750 lb. of water per hour according to size.

The Galloway boiler differs from the Lancashire boiler only in the form of the furnace tubes. Truncated conical tubes are

inserted in the main furnace tubes with the object of increasing the evaporative capacity of the boiler, and it has been found in practice that the normal increase amounts to about 10 per cent; thus on comparing two boilers, one Lancashire and the other of the Galloway form, 8 ft. by 30 ft., the heating surface of the former is found to be 985 sq. ft., whereas that of the Galloway boiler is 1164 sq. ft., and for equal quantities of coal (1424 lb.) the water evaporated by the former was 10,565 lb. and by the latter 11,485 lb., showing that the

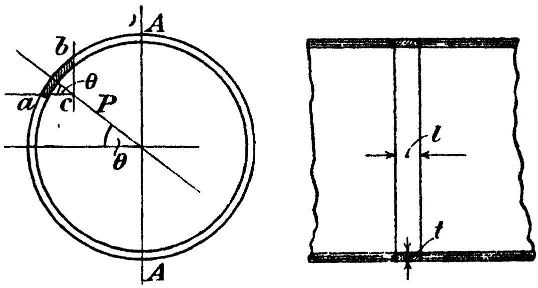


FIG. 5. STRENGTH OF SHELL.

evaporative powers were respectively 9·4 and 10·4 lb. of water per lb. of coal burned.

Construction and Strength of Shell. In discussing the theory of the strength of boilers, it is customary to regard a boiler as a thin cylinder having no longitudinal joints. Referring to Fig. 5, let P be the internal pressure in pounds per square inch, d the diameter of the shell in inches, t the thickness of the plate in inches, S the stress in the material in pounds per square inch, f the safe stress in pounds per square inch, l the length of a small element of length in inches, E the efficiency of the joint. Let ab be any element of arc, and project ab horizontally and vertically. The resultant internal pressure on an element ab = arc $ab \times P \times l$, and when ab is infinitely short the internal pressure equals P, and the direction of P is along the central radius of the arc. Assuming that the central radius is inclined at an angle θ to the normal to the plane AA,

the horizontal component of P, normal to the dividing plane AA, equals Pl arc $ab \times \cos\theta = Pl \times bC$, and since the bursting force is the sum of all such elementary forces, the total bursting force acting normally to the plane AA, equals Pld. The force resisting the bursting force when equilibrium exists $= 2tSl$, and consequently—

$$Pld = 2tSl, \text{ and } P = 2tS \div d, \text{ or } S = \frac{Pd}{2t} \text{ and } t = \frac{Pd}{2f}$$

Allowing for the efficiency of the joints, $t = Pd \div 2fE$. For single-riveted lap joints $E = 0{\cdot}55$, for double-riveted lap joints $E = 0{\cdot}7$, but for single-riveted butt joints with double cover plates $E = 0{\cdot}57$, and for double-riveted butt joints with double cover plates $E = 0{\cdot}77$.

The stress in the circumferential joints $= \frac{\pi}{4} d^2P$, and for equilibrium the resisting force equals πdts, hence $S = Pd \div 4t$, thus it is seen that the stress in circumferential joints is just half of the stress in longitudinal joints, and consequently we have an explanation for the necessity of double riveting longitudinal joints, while circumferential joints are single riveted.

Example 12. A Lancashire boiler 7 ft. 6 in. is to be constructed with butt joints, and double cover plates with double-riveted longitudinal joints to generate steam at a pressure of 150 lb. per sq. in by gauge. Assuming the safe stress of the mild steel used in the construction is 10,000 lb. per sq. in, find the thickness of the shell.

Solution. $t = \frac{Pd}{2fE} = \frac{150 \times 7{\cdot}5 \times 12}{2 \times 10{,}000 \times 0{\cdot}77} = 0{\cdot}87$ in.

Furnace Tubes. These are usually constructed of rings bent to a truly cylindrical form, the meeting edges being brought together and welded. The ends of the rings are flanged outwards, and the rings are connected by rivets passing through the flanges, as shown in Fig. 6. The figure also shows the methods by which the tubes are connected to the end plates. A feature of the Adamson joint is that the heads of the rivets are in the water space where they are unexposed to

the corrosive action of the sulphurous gases passing along the furnace tubes from the fire. Another feature of the joint is the welded expansion ring which is placed between the flanges to facilitate *caulking*, the process by which the joint is made steam-tight. The stability of the furnace tubes is secured by the number of flanged joints in them, just as a corrugated tube is stabilized by its corrugations. As shown in Fig. 4, the connection to the back end plate is made by the flange of the last ring of the tube, and it will be seen that the rings near the back are of smaller diameter than the others. This

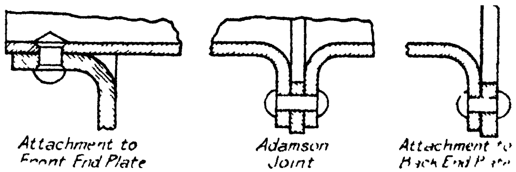


FIG. 6. SHOWING JOINTS IN FURNACE TUBES

construction is adopted to give access to the bottom of the boiler for the purpose of cleaning and inspection.

Furnaces. In the simplest case the furnaces consist of a fire-grate made up of bars of iron placed side by side, with an air space between each pair, the bars being supported on bearers resting on brackets, which are riveted to the sides of the furnace tubes. Fig. 4 shows the simplest arrangement of the fire-bars, and there it will be seen that a fire-brick bridge, or flame dyke, is constructed to prevent coal from being thrown over the end of the furnace and to restrict the space through which the products of combustion and air pass, so that by their proper admixture the combustion will be as complete as possible. The furnaces are closed by hinged doors provided with adjustable openings. The *dead-plate* is made long enough to prevent the hot fuel from coming right forward to the furnace doors, thus protecting the junction of the furnace tubes with the front end plate from the direct action of the fire. When the furnace is of this simple form, much energy is lost in black smoke and the incomplete combustion of the fuel.

Heywood Forced-draught Furnace. Fig. 7 shows in section and plan the principal features of this furnace, which has been designed to replace the common form of furnace fitted to

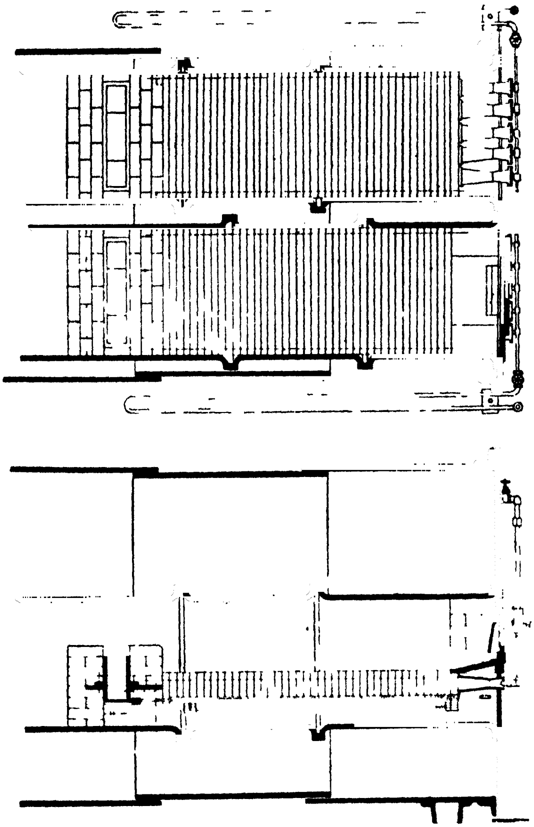


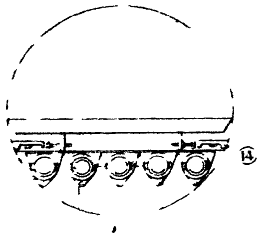
FIG 7. SECTIONS OF HEYWOOD FORCED DRAUGHT FURNACE

Lancashire boilers and others of the same type. In this case the fire-bars are placed transversely across the furnace tubes, and the bars are cast so that when they are placed in position they form a series of five tubes corresponding to the same

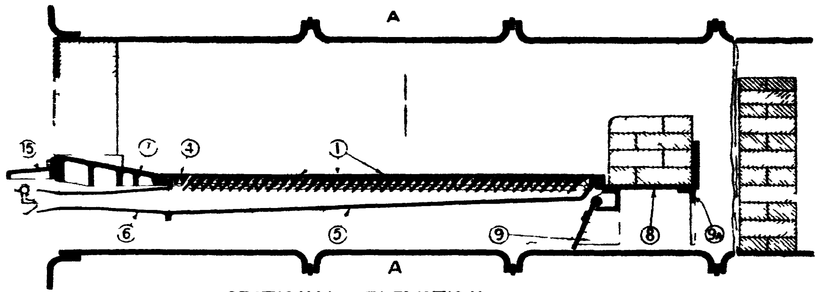
number of steam jets placed at the front of the boiler under the dead-plate The firebridge is shown to be constructed so that air from the ash pit may be admitted to the *back*-end of the furnace, the *damper* being operated by a handle shown in the upper portion of the figure immediately below the nozzles of the steam jets. With this apparatus it is possible to burn any class of fuel more efficiently than is possible in a plain furnace.

By the proper adjustment of the damper and the steam jets the issue of black smoke from the chimney is prevented; consequently the amount of water evaporated per lb. of fuel used is greater. The obvious result of the installation of such an apparatus is that a smaller number of boilers are required to provide the requisite amount of power; moreover, the furnace is capable of dealing with low-grade fuel such as is usually to be found in adequate quantities at coal mines. The steam used may be drawn direct from the boiler, or it may be given some superheat by passing the steam pipes through the side flues of the boiler.

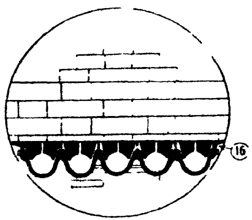
Turbine Furnace. This furnace is built on similar lines to the Heywood furnace, but it differs in the shape of the nozzles through which the superheated steam and air pass to the underside of the fire-grate. The nozzles of the steam jets bear a close resemblance to the nozzles of a De Laval steam turbine, and this form has been adopted in the endeavour to ensure that the air shall pass up through the fire at a uniform rate over the whole area of the fire. Fig. 8 shows a section of the furnace. Two results immediately follow the use of such an arrangement; firstly, there is no possibility of overheating the furnace tubes; and, secondly, there is little possibility of unconsumed carbon passing into the chimney, provided the steam jets and the bridge damper are properly controlled. The steam used for the jets is superheated after passing through a reducing valve. The use of superheated steam increases the efficiency of the injector jets as, for equal weights, the volume delivered is greater if the steam is superheated than it is if the steam is saturated. Tests which have been made show that



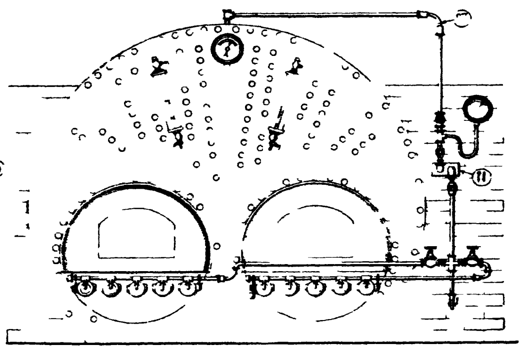
FRONT ELEVATION



SECTIONAL ELEVATION



SECTION AA



LIST OF PARTS

INDEX	NAME OF PART	MAT'L	Nº OFF	PART OF DRG Nº	NOTES
1	FIRE BAR	C I		G D2	
4	FIRE BAR LOCKING BAR			4/G.D2	
5	AIR TROUGH			G.D.101	
6	INJECTOR	"		A D21	
7	DEADPLATE	"		A D33	
8	BRIDGEPLATE	"		A D4.A	
9	CLEANING DOOR FRAME	"		A D5.A	
9A	BRIDGE SUPPORT	"		A D.52B	
11	SUPERHEATER WALL BOX	"		A D.62	
14	EXTENSION BRACKET	"		A D62	
15	ASH GUARD	"		A D63	
16	SIDE EXTENSION	"		2/A D63	
27	STEAM FITTINGS	AS REQUIRED			

FIG. 8. TURBINE FURNACE

the *draught* is adjustable within wide limits according to the steam pressure. It has been found that if the steam pressure is 10 lb. per sq. in., the pressure in the nozzles is 0·15 in. water gauge. A steam pressure of 20 lb. gives a water gauge of 0·25 in., and a steam pressure of 30 lb. gives an air pressure of 0·35 in. By varying the steam pressure the air pressure below the fire-bars can be regulated over a wide range, consequently a large variety of fuel can be burned in the same furnace at different times. As the result of tests which have been made

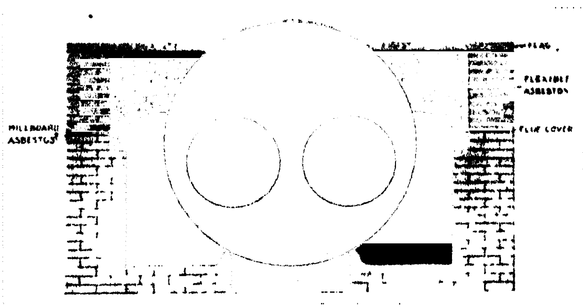


FIG. 9

it has been found possible to reduce the cost of generating electric power by one-half, the saving having been effected by the greater evaporative power of the boilers and the lower charges for fuel and maintenance

Seating and Covering the Boiler. The foundation upon which a Lancashire boiler is set is built in such a way as to provide a central passage by which the flue gases pass from the back of the boiler to the front, underneath the boiler, and two passages or side flues by which the gases pass along the sides of the boiler towards the main flue at the back of the boiler. Fig. 9 is a section showing the relative positions of the bottom and side flues, the form of the fire bricks upon which the boiler is set, and the *Hamer* method of covering the boiler with flexible asbestos to allow for the occasional expansion and contraction which takes place when the temperature of the boiler

changes The foundation and side walls are faced with fire-brick to withstand the high temperature of the flue gases Fig 10 shows the flues at the back of the boiler and exhibits the Hamer patent expansion joint, which is designed to prevent leakage of hot gases from the downtake to the side

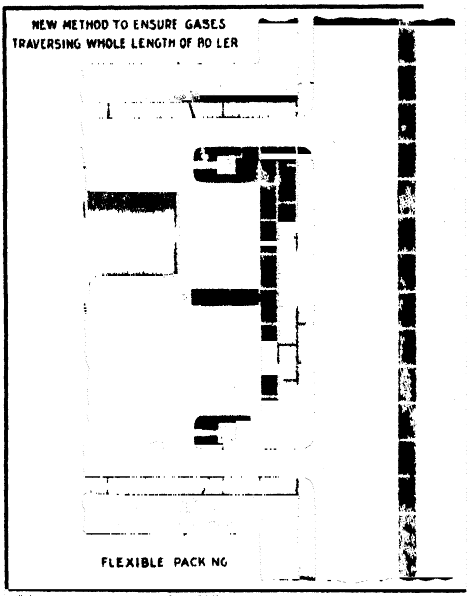


Fig 10

flues The obvious advantage of this construction is that the brickwork surrounding the boiler is undisturbed by the expansion of the boiler, consequently there can be no leakage of cold air to the flues with the result that the efficiency of the boiler is maintained at a high level In laying the foundations for a range of boilers it is now common practice to lay down a substantial raft of reinforced concrete with the object of preserving the brickwork surrounding the boilers in good condition and the foundations should be laid so that the boiler is about 1½ in lower at the front than at the back

The main objects to be aimed at in setting boilers are—

1. Accessibility of flues for examination and cleaning.

2. Allowing the minimum area of contact between the shell and the brickwork to avoid concealment of plates.

3. Deflection and distribution of gases in such a manner as to obtain the greatest effect from them.

4. Prevention of leakage between flues and between the outside atmosphere and the flues.

Babcock & Wilcox Water-tube Boiler. Fig. 11 shows this form of boiler in longitudinal and cross-sections, and it is seen to consist of three main parts, viz. : (1) a horizontal steam and water drum ; (2) a series of inclined water tubes ; (3) a series of header boxes. The steam and water drums, of which there are, as a rule, two in a battery, vary from 2 ft. to 4 ft. 6 in. in diameter and from 10 ft. 5 in. to 25 ft. 2 in. in length They are made of the best selected mild steel, with double riveted or butt-strapped joints. As will be seen in Fig. 11, the entire boiler, with the exception of the furnace, is suspended on wrought-iron girders and columns, thus enabling it to expand and contract without undue strain, and allowing of access to the surrounding brickwork without interfering with the support of the boiler. It is in this part of the boiler that the steam separates from the water. The inclined water tubes are of wrought steel, expanded at each end into sinuous boxes of steel, each connecting one zig-zag row of tubes. The end connecting boxes are provided with hand-holes for cleaning purposes opposite each water tube, the hand-hole covers being machined to form metal-to-metal joints, thus dispensing with all perishable material as ordinarily used in making joints. The covers are held in place by wrought-steel clamps. The end connecting boxes are attached to the horizontal steam and water drum by short tubes, expanded into accurately-bored holes, thus providing a large and continuous waterway through all the parts A mud collector is attached to the lower ends of the rear header boxes with the object of collecting suspended matter that passes down through them, and an

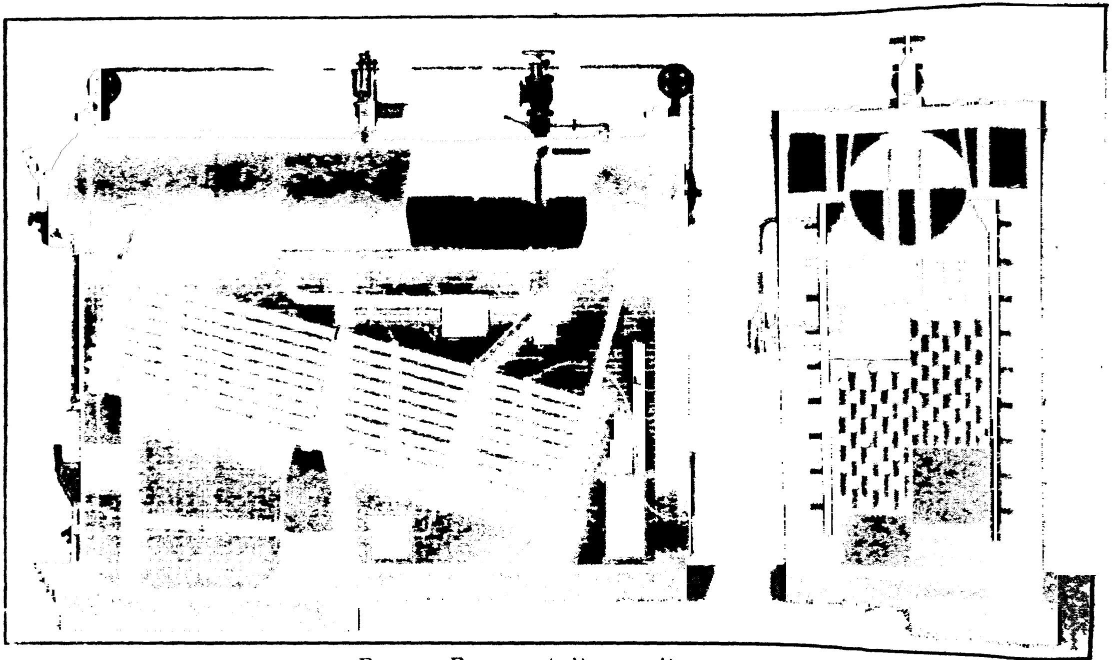


Fig 11 Babcock & Wilcox Boiler

arrangement is made whereby the sediment may be discharged from the collector under pressure of the steam in the boiler. The whole structure is built upon a bed of concrete, the main upright columns being placed on stone blocks at the corners of the foundations.

Action of the Boiler. In the longitudinal section of Fig. 11 the path of the hot gases from the furnace to the main flue

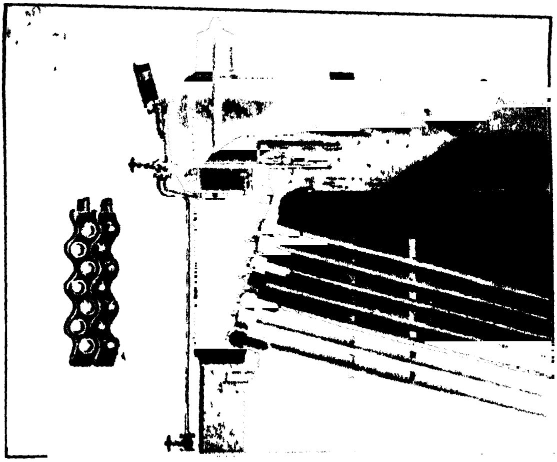


FIG. 12. ARRANGEMENT OF WATER TUBES AND HEADERS

is shown by arrows. The heat radiated from the furnace at the front of the boiler is conducted to the water within the inclined tubes, and as the temperature of the hot gases is greater at the front of the boiler than it is at the rear end of the inclined tubes, a definite convection current is established in the boiler. As shown in Fig. 12, the hot water and steam pass from the inclined tubes into the front header, thence to the steam drum; the hot water, now mixed with colder water, passes to the rear end of the steam and water drum, where it enters the downtake tubes, carrying with it such sediment as may have been precipitated at the temperature of ebullition.

The obvious principle involved in the action of the boiler

is the familiar one of counter currents, the gases losing heat to the water as they pass from the furnace through the baffled passages to the main flue. The effective heating surfaces are thin, the volumes of water in contact with them are small, and the hot gases impinge upon them directly because of the staggered arrangement of the tubes. It is a great advantage of the system of conducting the furnace gases through the combustion chamber that the gases should pass through amongst the inclined tubes three times before finally passing into the main flue. That arrangement is conducive to two things of the utmost importance in a steam plant, viz.: (1) rapid generation of steam; (2) high thermal efficiency and consequent economy in the use of fuel.

The feed water is introduced through a feed valve attached to the front end of the steam and water drum, and is directed backwards along the drum by a short internal pipe, this being the direction of flow resulting from the form of the boiler and the method by which the heat of the furnace is applied to the water tubes. The valve through which the steam leaves the boiler is situated near the rear end of the steam and water drum; therefore, it will be readily understood that as the steam liberated near the front end of the boiler has to pass back about three-quarters of its length, the generation of dry saturated steam will be promoted.

The Babcock & Wilcox boiler may be fired by hand or by some form of mechanical stoker, but it is not to be recommended that larger sizes of boiler should be hand-fired.

Stirling Boiler. As shown in Fig. 13, this form of water-tube boiler has three steam drums 3 ft. 6 in. in diameter connected to two mud drums, of the same length and 3 ft. in diameter, by bent tubes, which are 3¼ in. in diameter and enter the steam and mud drums radially. The water spaces of the steam drums are connected to the mud drums and to each other by tubes, and the steam spaces are likewise connected by tubes shown underneath the covering.

The drums and connecting tubes are supported on a framework of steel, and the enclosure is made by brickwork built

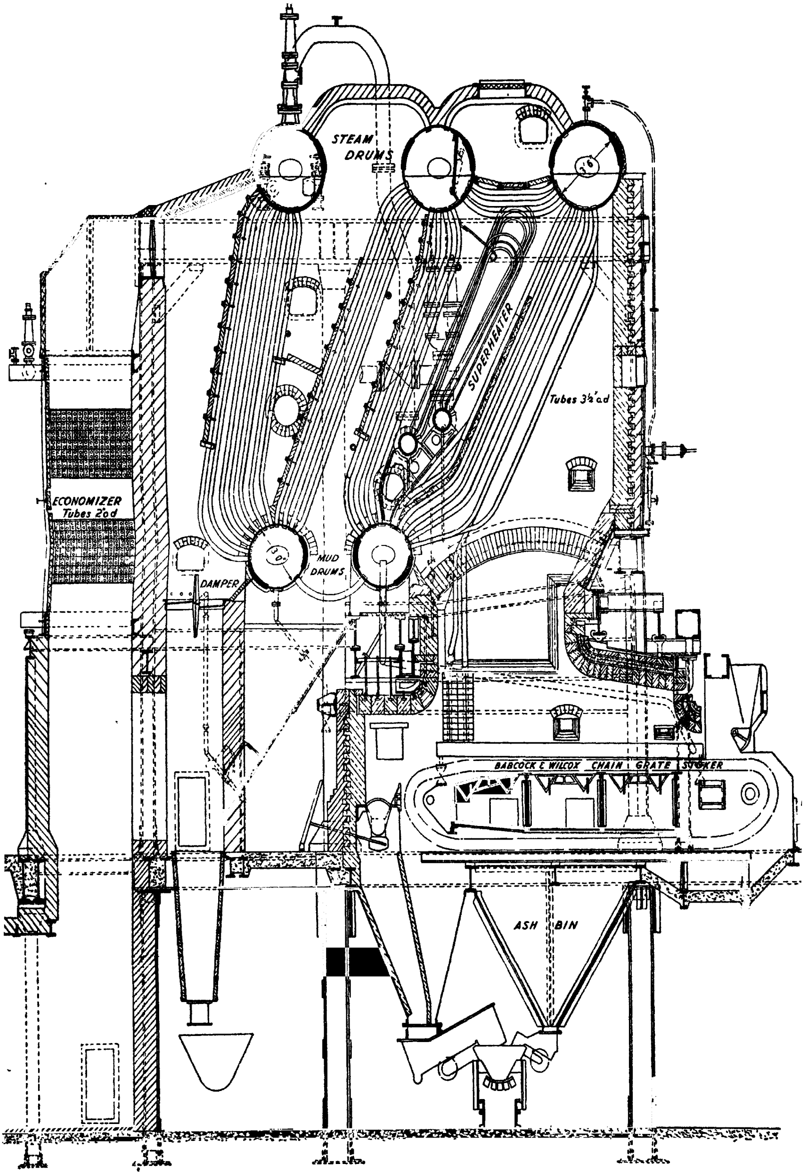


FIG 13. STIRLING FIVE-DRUM BOILER

Capacity: 60,000 lb. of steam per hour

(T.5468)

into the steel framework. The feed-water is delivered to the rear drum, from which it flows through the connecting tubes to the other steam and mud drums. The hot gases from the furnace at the front of the boiler are directed by partitions through among the water tubes and pass in the contrary direction to the water within the tubes. On account of the contrary directions of flow of the hot gases and the feed-water it is apparent that the most vigorous ebullition of steam will take place in the foremost steam drum, and when the saturated steam is to be superheated the superheater is placed in the front compartment of the heating system.

Coal is fed continuously on to the chain-grate stoker, and the ash is delivered into trucks placed at the inner end of the stoker. Draught is produced by a fan and a damper isplaced in the rear downtake leading to the chimney flue. Doors are provided at certain places in the brickwork to give access to the tubes and drums for the purpose of cleaning and overhauling the boiler.

Pitting and Grooving in Boilers. It has been observed that the plates of boilers tend to become pitted along the sides and on the top of the furnace tubes, and such pitting is not confined to the interior of boilers but may be seen on the fire side of the furnace tubes.

The effect of pitting is to reduce the effective thickness of the plates, consequently pitting is a source of danger that is the direct result of corrosion.

Grooving takes place as a rule near the junctions of plates, at the root of flanges, and the toes of gusset stays, and it is believed to be due mainly to unequal expansion and contraction of the plates in the region of joints, but it may also arise from electrolytic action of saline water at the junction of plates of even slightly different constitutions.

Incrustation in Boilers. The water used in boilers for the generation of steam may give an acid reaction, in which case the interior surface of the plates of boilers may suffer corrosion, but should the water contain mineral salts in solution it is most likely that scale will be deposited on the plates and form

carbonate, is used to convert the soluble sulphates into carbonates and non-scale-forming sulphate of soda, thus—

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

or with magnesium sulphate—

$$MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$$

the magnesium carbonate being removed by the addition of calcium hydrate as before

The hardness of water is determined in this country in degrees Clark by the titration of a measured volume of water with a standard soap solution The soap test is a ready means of determining whether water contains such salts as would form a loose deposit that might be blown out of the boiler by the blow-off cock or a hard scale that would have to be removed by chipping with hammer and chisel or other suitable tool but it is only upon the basis of chemical analysis that a method may be designed for the removal of scale forming ingredients before the water is fed into the boilers Table III shows that whereas the water of Loch Katrine is naturally soft and free from harmful impurities the water of the River Clyde would require treatment to remove both temporary and permanent hardness before use in a boiler if it was desired to avoid the formation of scale but it is seen that the pit water might be treated in a simpler manner for there are no ingredients which form hard scale

Filtration of Precipitate When water has been treated for the precipitation of scale forming constituents it is necessary to filter it as it passes on to the feed pumps The operation is best performed in a gravity filter consisting of a shell of steel reinforced concrete, brick, or stone, containing a filter bed formed by layers of graded quartz sand resting on layers of pebbles, the depth of the bed being three or four feet Rapidity of filtration is ensured by agitating the filter bed with compressed air and a reverse current of filtered water by which the sediment is carried into the drain The Paterson Engineering Co Ltd make also a pressure filter when the natural head is insufficient for gravity filtration

REFERENCE BOOKS

Applied Thermodynamics by Robinson
Steam and Other Engines, by Duncan
Mechanical Engineering for Beginners, by Maclaren
Textbook of Heat Engines by Jamieson and Andrews
Water Softening and Purification by Collet
Purification of Industrial Waters by Paterson Engineering Co., Ltd
Boiler Feed Water by Simpkin and Dawe

EXERCISE QUESTIONS

1 Enumerate the chief points to which you would give consideration in deciding upon the boiler plant most suitable for colliery use

2 In arranging the steam boiler plant at a modern colliery, state the appliances you would install to ensure economy in fuel consumption, and state what percentage of the total output of coal should be regarded as the maximum to be used in the generation of steam power What class of boiler do you prefer for colliery work, and why?

3 What is hardness in a boiler feed water? Some boilers are regularly blown off the water level in the gauge glass being lowered an inch or so Why is this done?

(2nd Class Exam May, 1931)

4 Make a drawing with dimensions of the Adamson joint for connecting flue tube sections of a Lancashire boiler The flue tubes are made of plates ½ in thick and are 3 ft internal diameter

(2nd Class Exam Nov., 1931)

5 Describe two types of arrangement of front for a Lancashire boiler Illustrate by detail sketches how the front plate is attached to the shell and how the flues are attached to the front plate

(2nd Class Exam May, 1934)

6 Describe what you may expect to see on looking at the front of a Lancashire boiler under steam Deal with the fittings and the riveting *(2nd Class Exam* Nov., 1938)

7 What type or design of valve or cock would you use for the following purposes—

(*a*) To control the steam supply from a Lancashire boiler

(*b*) To control the blow off or emptying of a Lancashire boiler

(*c*) For use by the driver in supplying steam to a winding engine,

(*d*) To prevent the water in a rising main from running back when the pump stops? *(2nd Class Exam* May, 1939)

8 Describe the setting for a Lancashire boiler (say 28 ft by 8 ft diam), one of a range of boilers How is the draught through the fires controlled? *(2nd Class Exam* May, 1939)

9. Explain carefully what causes certain waters to be bad for feeding boilers. When a bad feed-water has been treated to make it suitable for use in boilers, does it behave within the boiler in the same way as a good untreated water? Explain your answer.

(*1st Class Exam.*, May, 1931.)

10. Describe a boiler of the Stirling type, i.e. with bent, highly inclined tubes illustrating your answer with a simple sketch showing a side elevation of the boiler. What is the usual diameter of the water tubes? (*1st Class Exam.*, May. 1931.)

11. Describe a Lancashire boiler. Name approximately the largest Lancashire boilers made (length and diameter). State the highest steam pressure for which Lancashire boilers are suitable.

(*2nd Class Exam.*, Nov., 1931.)

12. The longitudinal joints of the plates in a Lancashire boiler are of the butt type, with the following specifications: Plate thickness, 1 in.; rivet holes, 1 in. diam.; cover plates, 9¼ in. wide, rows of rivets, 4; spacing of rivets longitudinally, 3 in.; spacing of rows of rivets transversely from one side of the cover plate to the other, 1¾ in., 1½ in.; joint, 1½ in., 1¾ in.

Make a plan of this joint to a scale of one-quarter full size, showing a length of about 18 in. of the joint. The rivet holes can be indicated by crossed centre-lines at the correct points, except for one hole in each row, which should be shown correctly to scale. Show all necessary dimensions and ignore the curvature of the shell plate. (*1st Class Exam.*, Nov., 1931.)

13. Describe one type of water-tube boiler, say for a duty of 10,000 lb. per hour of steam at 175 lb. per sq. in. State in detail how the tubes are secured in the headers or drums so as to obtain a steam-tight joint. (*1st Class Exam.*, May, 1932.)

14. Describe the construction of a modern Lancashire boiler for a working pressure of 120 lb. per sq. in. Deal in detail with the shell and tubes. A list of fittings and mountings is NOT wanted.

(*1st Class Exam.*, Nov., 1932.)

15. Describe a modern steam-raising plant to provide superheated steam at a high pressure at the rate of, say, 40,000 lb. per hour. (*1st Class Exam.*, May, 1934.)

16. Describe the action of an injector for feeding water to a boiler. Illustrate your answer by a diagram or sketch.

(*1st Class Exam.*, May, 1934.)

17. Describe in detail the work of cleaning a Lancashire boiler from the time when it ceases to supply steam to the time when it commences to supply steam. (*1st Class Exam.*, May, 1938.)

18. A Lancashire boiler at a colliery is 30 ft. long by 8 ft. 6 in. diameter, with flues 3 ft. 6 in. diameter.

Coal of poor quality is burned. Quote a possible figure for the heat value of the coal in B.Th.U. per lb.

What weight of coal might be burned per hour in the boiler? What weight of water might be evaporated per hour to steam at 120 lb. per sq. in.? How often would you expect to clean the boiler fires? *(1st Class Exam.*, May, 1939.)

19. In Lancashire boilers what kind of joint is used

(*a*) for joining one end of a plate to the other end to form a shell ring;

(*b*) for joining one shell ring to the next;

(*c*) for joining the front plate to the shell and to the flue tubes? Illustrate your answer by sketches.

(2nd Class Exam., May, 1937.)

20. How may water be fed into a steam boiler under pressure? Describe a complete installation for feeding a boiler.

(2nd Class Exam., May, 1934.)

21. How is a tight joint made between

(*a*) A water tube and the drum of a water tube boiler;

(*b*) A gauge glass and the top and bottom gauge cock fittings;

(*c*) A cover and a man hole on a steam boiler?

(2nd Class Exam., Nov., 1935.)

CHAPTER III

BOILER ACCESSORIES

SECTION 56 of the Coal Mines Act requires that every steam boiler used for generating steam in or about a mine must have attached to it a proper safety valve, and also a proper steam gauge and water gauge, to show respectively the pressure of steam and the height of the water in the boiler; the boiler

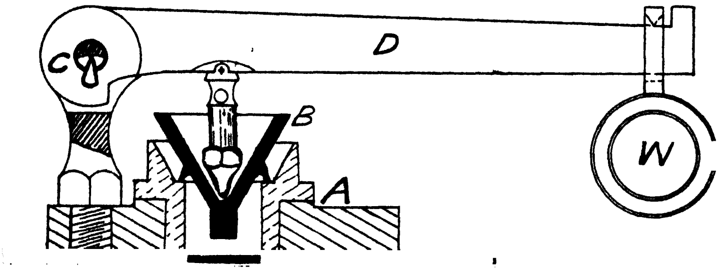


FIG. 14. LEVER SAFETY VALVE

shall be examined at least once in every fourteen months, and cleaned out and examined internally, as far as the construction of the boiler will permit, by the person in charge of it, once at least in every three months. These accessories will now be described.

Lever Safety Valve. Fig. 14 shows, partly in section, a lever safety valve. *A* is the body of the valve, *B* is the valve resting in a gun-metal seat in the body, *C* is the fulcrum about which turns the lever *D*, and *W* is the weight by the adjustment of which the steam is allowed to blow off at any pre-determined pressure. The valve opens when the counter-clockwise moment of the force of the steam on the valve is equal to the resultant of the clockwise moments of the weight and the lever about the fulcrum. Let d be the diameter of the valve in inches, p the pressure of the steam in pounds per square inch, w the

weight of the valve in pounds, W the weight in pounds, w_1 the weight of the lever in pounds, d_1 the distance from the fulcrum to the centre of the valve, d_2 the distance from the fulcrum to

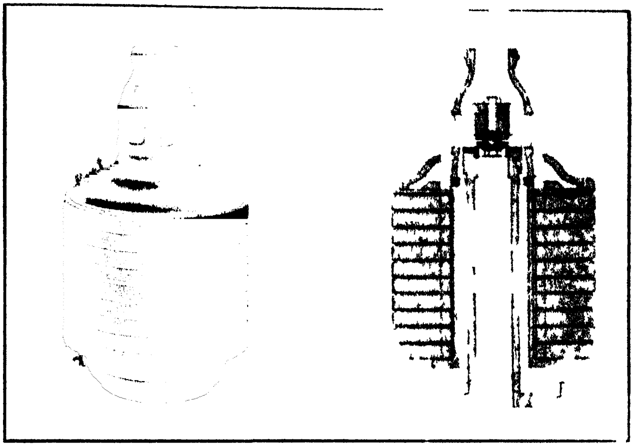


FIG. 15.—DEAD WEIGHT SAFETY VALVE

the centre of gravity of the lever and d_3 the distance from the fulcrum to the line of action of the weight, then

Clockwise moments = counter clockwise moments

$$W d_3 + w_1 d_2 = \left(\frac{\pi}{4} d^2 p - w\right) d_1$$

$$W = \frac{\left(\frac{\pi}{4} d^2 p - w\right) d_1 - w_1 d_2}{d_3}$$

Example 13. A valve weighing 4 lb. is 3 in. in diameter, and the distance from the centre of the valve to the fulcrum is 4 in. The weight of the lever is 10 lb. and the distance from the fulcrum to the centre of gravity is 10 in. The lever is 22 in. long. Calculate the weight that must be hung on the lever at the distance of 22 in. from the fulcrum in order that the steam may blow off at a pressure of 60 lb. per sq. in.

Solution. $W = \dfrac{(0{\cdot}7854 \times 3^2 \times 60 - 4)\ 4 - 10 \times 10}{22}$

$= 71{\cdot}8\ \text{lb}$

Dead-weight Safety Valve. Fig 15 gives two views of a valve of this type, and it is seen that the valve consists of a

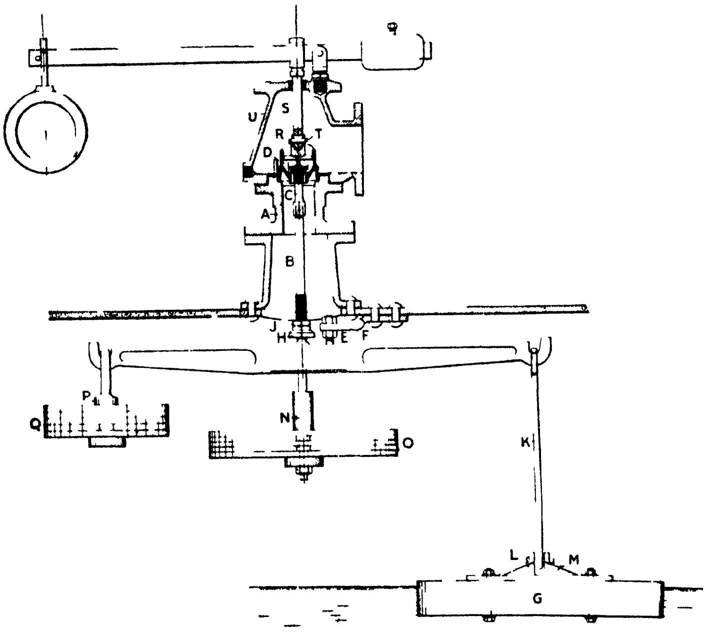


FIG 16 HIGH PRESSURE AND LOW WATER SAFETY VALVE

pipe that is attached to the mounting block on the top of the boiler, the valve surmounting the pipe, and both being enclosed by a case that hangs from the valve. The case contains the weights sufficient to keep the valve on its seat against the normal pressure of the steam The combined weights of the valve, case, and weights must be equal to the pressure of the steam in pounds per square inch, multiplied by the area of the

valve exposed to the action of the steam, thus: $W = 0{\cdot}7854d^2p$. Such valves require frequent examination and cleaning to ensure that steam blows off at the desired pressure, for they are liable to get silted up with mineral matter carried through the valve with the steam.

Low-water and High-pressure Safety Valve. This valve is designed to blow off when the steam pressure is high enough to overcome the moment of the weight combined with that of the lever about the fulcrum, or when the level of the water in the boiler becomes dangerously low. Fig. 16 gives a section of the valve. The arrangement consists of an outer body *A*, which contains the outer valve *D* and the inner valve *R*, the latter resting on a seat formed in the outer valve, being held down by the weights *O*, through the medium of the rod *B*. The outer valve is the high-pressure valve, and when the pressure of the steam attains the blow-off pressure the outer valve, together with the inner one, is raised from its seat against the combined forces of the weight on the lever and the weights hanging on the rod *B*. A tile-float *G* hangs at the end of a rod *K*, and *Q* is a balance weight at the other end of the lever which is pivoted at the point *E*. *H* is a collar, the position of which is adjusted by the nut *J*, and it will be seen that as the level of the water in the boiler falls the float also falls and raises the balance weight, and when the float falls dangerously low, knife-edge on the lever engages with the collar attached to the rod *B* and opens the inner valve to the escape of steam.

Reducing Valve. Fig. 17 is a sectional view of a Hopkinson reducing valve. The function of such a valve is to effect the reduction of the pressure of the steam generated at high pressure to suit the requirements of engines driven by steam at a lower pressure, and their use is a necessity where the boilers in a range are not all generating steam at the same pressure. The inflowing steam is admitted between the valve *B* and the piston *K*, which is covered by an india-rubber diaphragm *H*. The piston and the valve are in equilibrium on the inlet side of the reducing valve. A column of water *E* is interposed between the steam and the diaphragm, and the

column is maintained by the condensation of steam entering the valve. The nut N is adjusted until the pressure of the steam on the outlet side of the valve is that required. The compression of the spring is accompanied by the opening of the valve, which is not now in equilibrium under the differential

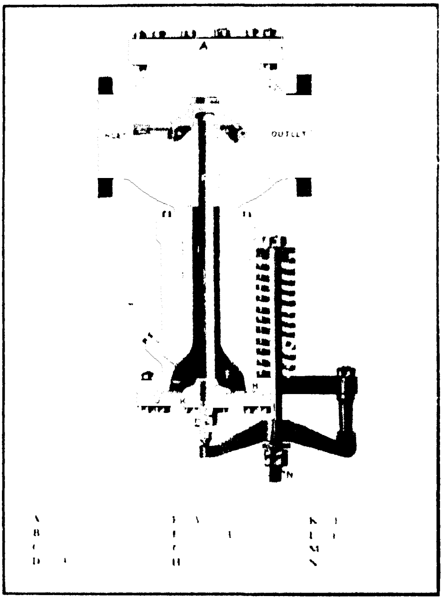


Fig. 17. Reducing Valve.

pressure of the steam on its upper and lower faces. But the difference of pressure is balanced by the pressure exerted by the spring.

Hopkinson-Ferranti Steam Stop Valve. This valve was invented by the famous electrical engineer S. Z. de Ferranti, and it embodies a principle enunciated in the "theorem of Bernouilli." Since the total energy in unit mass of a fluid flowing through a tube of varying diameter is constant, it is apparent that the kinetic energy in unit mass of steam flowing

through a Hopkinson-Ferranti stop valve (Fig. 18) nust reach a maximum in passing through the throat, and consequently the pressure energy there must reach a minimum value. The illustration shows that the steam passage is convergent

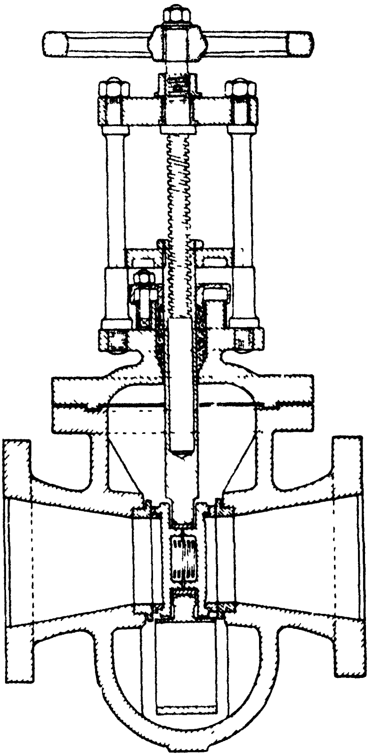


FIG. 18. THE FERRANTI STEAM STOP VALVE

towards the valve and divergent away from the valve. There is, therefore, less effort required to open the valve than if the conduit had been of the usual cylindrical form, and as the interior surfaces of the throat and the vestibules are smooth, there is no serious loss of energy occasioned by the passage of the steam through the contracted pipe.

Pressure Gauge. Fig 19 shows the internal construction c a steam pressure gauge It consists of a hard-drawn phosphoı bronze or steel tube of oval section, bent to form, the free en being connected by linkwork to toothed segment whic engages with the pinion wheel on the axis of the gauge pointeı As the steam pressure increases the tube tends to straighten

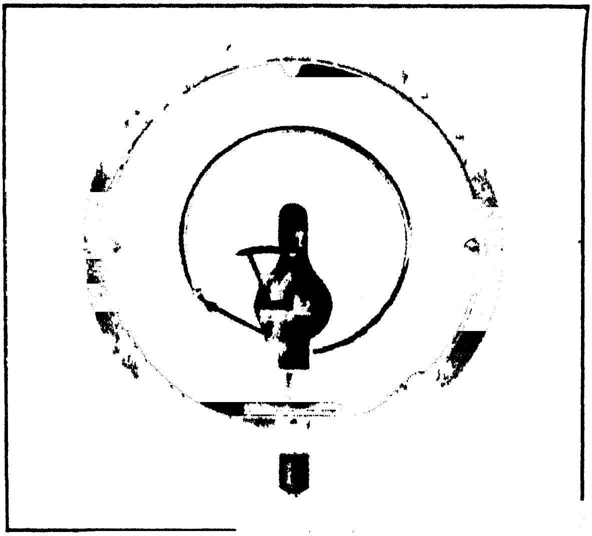


Fig 19 Pressure Gauge

and the variation of the steam pressure is registered by the movement of the pointer round the graduated arc of pressures The gauge is usually provided with a siphon to prevent overheating of the gauge tube thus ensuring accuracy and freedom from breakdown

Water Gauge. Fig 20 shows partly in section, a Hopkinson water gauge for registering the height of the water in a boiler It is necessary that the gauge should be arranged to automatically cut off the escape of steam and water should the gauge glass break and it must be capable of being tested from time to time at the discretion of the stoker This latter quality

of the gauge is rendered necessary by the fact that false water-levels are sometimes registered. When the steam and water cocks are open the water and steam flow into the gauge glass,

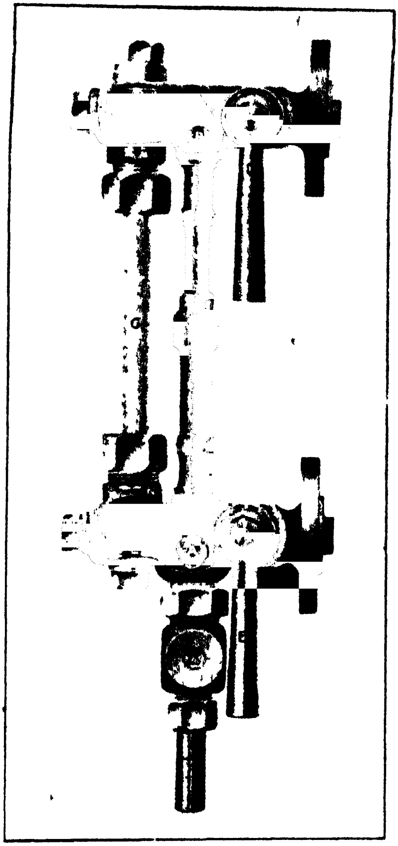


FIG. 20. WATER GAUGE.

but should the glass break the balls *A* and *B* are swept into the positions indicated by the dotted circles to prevent the escape of steam and water. A further protection against scalding is provided by the use of guards of thick glass

surrounding the gauge glass. The gauge should be tested several times daily by blowing steam through the tube *G* and out at the cock *F*.

Feed-water Valve. Fig. 21 shows the internal construction

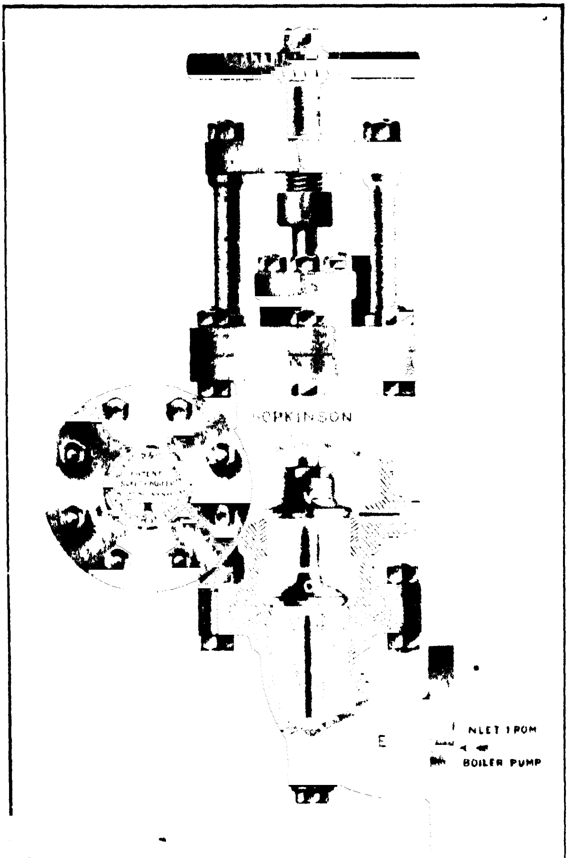


FIG. 21. CHECK-FEED VALVE

of check-feed valve. The valve and its housing are attached to the front of the boiler in a position below the water-level

pointer, or in special circumstances it may be mounted on the top of the boiler. It is seen that the automatic valve *C* is controlled by the valve *V*, which is operated by the hand-wheel. The latter is an adjunct which has been rendered necessary to prevent the return of the water from the boiler generating high-pressure steam on the cessation of the action of the feed pump. The level of the water in the boiler is controlled by the wheel valve, and it is clear that the automatic

FIG. 22 TANGYE DUPLEX FEED PUMP.

valve may be re-conditioned while the boiler is under steam. The working parts are made of bronze and the body is made of cast steel.

Feed Pump. Fig. 22 represents a duplex boiler feed pump capable of supplying water to a boiler at pressures up to 220 lb. per sq. in. The piston rods are of steel, fitted with cast-iron pistons and rings; the stuffing-box glands are of brass in the smaller sizes of pump, and of cast iron with brass bushes in the larger pumps. Pumps of this class are fitted with cast-iron adjustable buckets packed with compressed canvas, or with brass buckets when hot water has to be dealt with In either case the cylinders are fitted with brass liners that are easily renewable. The valves and seats are of brass, and the valves are controlled by brass springs. On examination of the water end

of the pump it is seen that the valve cover can be removed without breaking any pipe joint. Plugs are fitted for draining the steam cylinders. This pump is made in sizes varying from 3 in. by 1½ in. by 3 in. to 10 in. by 8 in. by 10 in. and capable of delivering from 90 to 7800 gallons of water per hour at bucket speeds of from 10 to 30 ft. per minute. There are two steam cylinders and two pumps, and it is seen that the valve of the nearer engine is operated by a crank driven by the other engine, the connection being made to a bolt attached to the piston rod in the manner shown in the figure. Both engines are operated in this way. No air vessel is shown in the figure, but that may be attached when necessary. Turbine pumps are now being used to feed boilers; they possess the advantage that they need not be stopped when the boilers have been fed, for even if the valve in the delivery pipe be closed down the impellers of the turbine will merely absorb a little power in churning the water in pump casing, and when the demand is made for water by the stoker opening the feed valve the pump will immediately deliver water to the boiler.

Feed Heaters and Economizers. The exhaust steam from non-condensing engines may be used to heat the feed water as it passes from the feed pump to the boiler. This may be done by passing the feed water through a heater. Such a heater consists of a number of brass tubes arranged vertically inside a cast-iron casing, the tubes extending between two partitions at either end of the heater, which usually occupies the vertical position. The steam inlet is near the bottom of the space between the partitions, the outlet being near the top. The water inlet is at the top of the heater and the outlet at the bottom, thus employing the principle of counter currents. A blow-off valve is attached to the bottom of the heater, and a door is provided to enable sediment to be cleaned out periodically. When it is desired to heat the feed water by means of the waste gases passing from the boiler furnaces an economizer may be used. This is an appliance which forms part of a steam plant when it is desired to effect some measure of economy in the consumption of fuel by heating the feed

water on its passage through the pipes leading from the feed pump to the boiler. The temperature of the feed water may be increased by 100 per cent as it passes through the economizer. If, for example, feed water is heated from 77° F. to 194° F. in its passage through an economizer, the amount of heat recovered from the flue gases per pound of feed water is

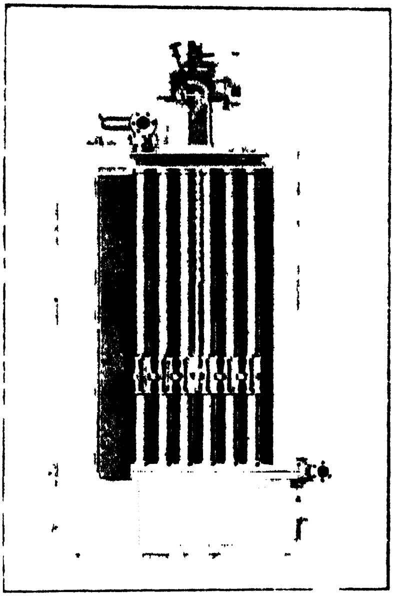


FIG. 23. GREEN'S ECONOMIZER

(194 − 77) = 117 B.Th.U., and should the total heat per pound of steam be 1170 B.Th.U., the efficiency of the economizer would be 10 per cent. Investigations show that the saving effected by the use of an economizer may be considerably greater than 10 per cent. Green's is a well known economizer of this type, and consists of a number of vertical tubes through which the feed water is pumped. The tubes are arranged in groups and are placed in the main flue between the boilers and the stack. Fig. 23 shows the arrangement of the tubes and the

manner in which they are connected together at the top and bottom. The water ascends the tubes as it is heated, and the tubes are connected so that the water flows through the economizer in the opposite direction to the flue gases, thus ensuring the maximum recovery of heat from the flue gases. Soot and tarry matter are deposited on the tubes, and would reduce the efficiency of the economizer were it not for the action of the scrapers, which continually scrape the deposit from the tubes. The deposit is allowed to collect in the soot pit, from which it is removed periodically. The illustration shows the mechanism by which the scrapers are operated and the lever safety valve which is ordinarily fitted to the hot-water pipe to guard against undue generation of steam pressure.

Superheater. The apparatus in which the additional heat is imparted to saturated steam is called a superheater. Fig. 11 shows the form of superheater attached to the Babcock & Wilcox tubular boiler. It consists of a number of U tubes, which are secured at each end to horizontal boxes and placed in the combustion chamber just under the steam and water drum. Steam is conveyed to these tubes by means of vertical pipes connected to the bottom of the steam drum, and it is seen that the pipes convey the steam to the upper connecting box and from the lower connecting box to the stop valve on the top of the boiler. As the steam passes through the superheater its temperature may be increased by 50 per cent, thus the steam is dried and the loss by condensation during transmission and in the engines using it is less than it would be if saturated. It follows that there is less liability to accident with engines that work intermittently. Due to the higher temperature of superheated steam, engines using it must be lubricated with oil having a higher flash-point and greater body than that used in lubricating engines using saturated steam, and it is necessary that a high-class packing material, preferably metallic packing, should be used in the stuffing boxes of the engines. The superheater attached to Lancashire boilers is similar in construction to that shown in Fig. 11, and they are usually placed in the downtake flue at the rear of the boilers

so that the hot flue gases pass through the tubes on their way from back to front of the bottom flue.

Induced Draught. There are three methods of inducing the draught necessary for the complete combustion of the fuel used in firing boilers, and these are: (1) by a chimney; (2) by means of a fan in circuit with the main flue; (3) by a fan out of circuit with the flue. The first method is commonly used at collieries, but either of the other methods may be used where a chimney has already been installed and found to give an inadequate draught for the proper combustion of fuel, either because the fuel is of a lower grade than had been used formerly, or because the later installation of economizers, and possibly superheaters, had so increased the resistance to the passage of the flue gases that the draught was inadequate. Local building regulations may require that a chimney should not exceed a certain height which would be quite inadequate for the production of draught by the simple process of aspiration, and in consequence a small chimney may have to be built, the additional draught being induced by means of a suitable fan.

Chimneys. Chimneys of a permanent character are built of brick to a height and of a diameter dependent on the amount and quality of the coal to be burned per hour, but if the structure is to be temporary it may be made of steel, in sections of suitable length, to facilitate transport and erection. As a rough guide, chimneys 100, 130, and 165 ft. high will give a draught suitable for burning 20, 25, and 30 lb. of bituminous steam coal per square foot of grate area per hour respectively. The practice followed in building brick chimneys is to make the diameter at the base not less than a tenth of the height, the batter on the outside being 0·3 in. to the foot. The thickness of brickwork at the top may vary from one brick to one and a half bricks thick, the thickness being increased by half a brick for each section of 25 ft. from the top, and it is usual to build a firebrick lining from the base to a height of 50 ft., with an air space between that and the outer brickwork.

The area of cross-section of a chimney at its smallest part

may be ascertained by the formula, $A = 0{\cdot}062Q \div H$, where A is the area in square feet, Q the quantity of coal burned per hour in pounds, and H the height of the chimney, is dependent on the temperature of the flue gases at the base of the chimney and the desired intensity of draught. The relation between the height of the chimney in feet and the water gauge in inches is given by the formula, $p = H\left(\frac{7{\cdot}6}{t} - \frac{7{\cdot}9}{T}\right)$, where t and T represent the absolute temperature of the outside air and the flue gases at the base of the chimney respectively in degrees Fahrenheit. The average water gauge given by colliery boilers is about 1 in. at the base of the chimney and 0·4 in. in the side flues. The temperature may vary from 240° F. to 750° F., according to the steps taken to economize heat, and in practice should more closely approach the lower figure than the higher one. There is a considerable difference of opinion regarding the advantages of chimney draught, but there is little doubt that the chimney as a draught-producer is a thoroughly unwieldy and inefficient appliance.

Example 14. Calculate the height and internal diameter of a chimney suitable for producing the draught necessary for the combustion of 6000 lb. of coal per hour, assuming that the temperature of the flue gases at the base of the chimney is 500° F. and that of the outside air is 60° F.

Solution. Let the required water gauge p be 1·25 in., then by the formula,

$$p = H\left(\frac{7{\cdot}6}{t} - \frac{7{\cdot}9}{T}\right), \text{ we have } 1{\cdot}25 = H\left(\frac{7{\cdot}6}{459 + 60} - \frac{7{\cdot}9}{459 + 500}\right)$$

$$= H\,(0{\cdot}0146 - 0{\cdot}0082)$$

$$\text{and } H = 1{\cdot}25 \div (0{\cdot}0146 - 0{\cdot}0082) = 195 \text{ ft.}$$

By the formula $A = 0{\cdot}062Q \div \sqrt{H}$, we have $A = \frac{0{\cdot}062 \times 6000}{\sqrt{195}} = \frac{372}{13{\cdot}9} = 26{\cdot}76$ sq. ft., and therefore the diameter of the chimney would have to be 5·9 ft.

Induced Draught Fans. Fans of the Sirocco type are suitable for use in connection with boiler plants, and in one case

the fan may be in circuit with the flue, the whole of the flue gases passing through the fan, but the fan may be out of circuit with the main flue being placed in a by-pass connecting the main flue with the base of the chimney. In the former case the fan deals with the total volume of flue gases and must therefore be comparatively large, whereas in the latter case the fan may be smaller, since it only deals with a portion of the flue gases. When the latter arrangement is used the gases are discharged by the fan into the throat of a Venturi chimney. A Venturi chimney is one which rises as a cylinder from its base, and at a certain height has a gradually diminishing diameter down to the diameter of the cylindrical throat, upon which is built a divergent section tapered to the top of the chimney. As the gases issue from the fan inlet into the base of the throat of the chimney at a high velocity, the pressure there is reduced below the pressure of the atmosphere, and consequently a current is established in the main flue and in the individual flue of the several boilers. This system possesses the distinct advantages that the structure may be small and that the volume of air passing in to the boiler furnaces can be regulated by regulating the speed of the fan, but if the installation was a large one several draught units would be necessary

Mechanical Stokers. The main object aimed at in the use of mechanical stokers is the uniform distribution of coal over the area of the boiler furnace in order that there will always be a red fire at such a temperature as to ensure that combustion will be complete and smokeless. Coal may be spread over the fire from above, the grate being fixed or moving, or it may be pushed up from under the level of the fire-bars by means of a ram or plunger, the ash being carried to an ash-pit behind the grate or allowed to fall through the fire-bars into the ash-pit under the fire-bars.

Underfeed Stoker. Fig. 24 shows the underfeed mechanical stoker in section in the furnace tube of a Lancashire boiler. *A* is the retort or fuel magazine, in the lower or circular part of which revolves a tapered feeding worm which conveys the coal to the furnace proper. *B* shows the terraced grates, *C* the

wind box, and *D* the fresh coal, which, being gradually pushed up to the burning point, has commenced to burn at the point *E*, where it meets the incoming air from the tuyeres *F* and F^1. Here the coal is coked, and the volatile combustible constituents mix with air admitted through the air inlets in the fuel magazine. As the only way of escape is through the mass of glowing solid fuel above, the volatile combustible constituents are ignited on rising to the surface of the fire and burn

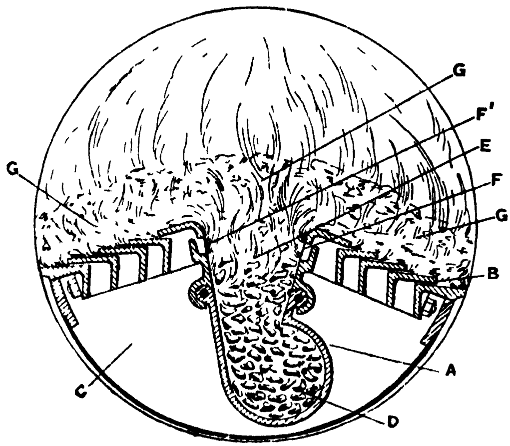


FIG. 24 UNDERFEED STOKER

smokelessly, provided the draught is regulated, while the combustion of the solid portion of the fuel is completed by the air introduced through the apertures in the sides of the terraced grate at *B*. The effect of this method of feeding is to keep a perpetually clear, bright surface of incandescent fuel which always produces its maximum steaming effect upon the boiler without the inevitable fluctuations of furnace temperature consequent upon hand-firing.

Babcock & Wilcox Chain-grate Stoker. Fig. 25 shows the general arrangement of the chain-grate stoker. It consists of an endless chain of short cast-iron grate bars linked together, and as the endless chain passes over drums at the front and

rear of the grate it can be driven from a shaft running across the front of the boiler. The front drum is caused to rotate by worm gearing, and gearing is provided to enable the whole stoker to be run back clear of the front of the boiler. The

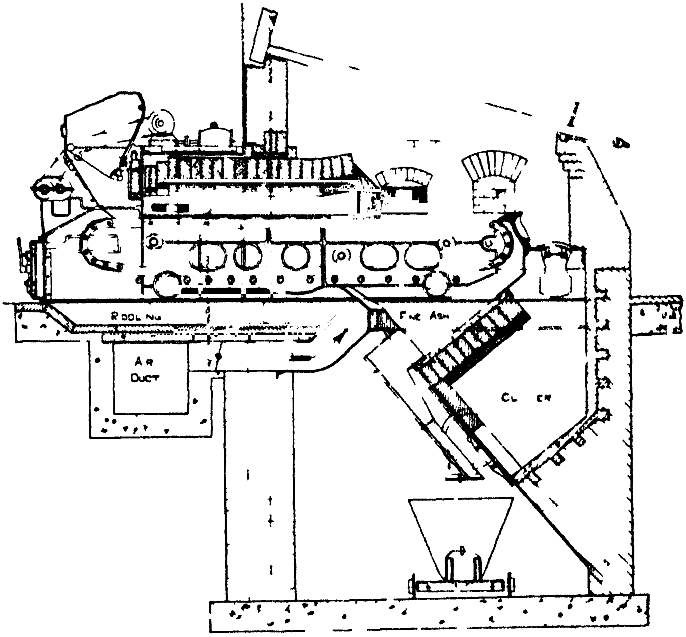


FIG. [illegible]. BABCOCK & WILCOX CHAIN GRATE STOKER.

coal which is fed into the hopper placed at the front of the furnace is delivered to the chain and is spread uniformly over the whole width of the grate, the thickness of the fuel bed being regulated by the vertically sliding arrangement of doors at the discharge of the hopper. These doors are arranged so that in an emergency the boiler may be fired by hand. The coal is carried forward to the ash pit at the back of the grate at a speed of from 5 to 15 ft. per hour according to the character of the coal used and the intensity of the draught. As the links

are made so that there is no relative movement between them, the coal remains undisturbed until it is reduced to ash, when it falls into the clinker pit. As is seen on referring to Fig. 25, the ash and clinker are removed in trucks.

Having regard to the necessity, or desirability, of using natural draught when burning coal of average heating power, and mechanical draught when burning coal of lower grade, Messrs. Babcock & Wilcox have devised the well-known balanced draught system. Their "enclosed" type stoker is completely enclosed without in any way altering the original design or losing any of the particular advantages of the standard chain-grate stoker, the only essential alteration being that provision is made for introducing air under pressure on the underside of the grate. When burning coal of average quality, the ash-pit doors are left open to allow the furnace to be fed with air under natural draught conditions, and when poor fuel has to be consumed the front doors of the ash-pit are closed, and the air is admitted to the ash-pit under pressure. The operation of changing from natural draught to balanced draughts, or vice versa, can be effected in a few moments. The use of this system admits of complete control over the regulation of the draught, and consequently various grades of coal may be efficiently consumed merely by making the necessary adjustments of the draught to suit the quality of the coal, the thickness of coal deposited on the grate, and the speed at which the chain is driven.

Steam Pipes. The pipes used to convey steam from the boilers to the engines at a colliery are made of cast-iron or of steel, the former metal being used for pipes of comparatively small diameter and the latter for pipes of the larger diameter used to convey large quantities of steam per hour. In either case the flanges are made solid, and the pipes are carried on brick or steel supports. Anchorages are provided between the positions of expansion joints so that the latter may function properly, and it is necessary that water traps should be attached to the pipes at suitable points to enable the water of condensation to be automatically removed as it accumulates.

Flow of Steam through Pipes. When steam flows through a pipe pressure is lost in overcoming the frictional resistance of the pipe, and experiments have shown that the loss of pressure is proportional to the square of the velocity of the steam and of the length of the pipe and inversely proportional to the diameter of the pipe. If c be a coefficient which depends on the roughness of the interior of the pipe we may write that the loss of pressure –

$$h = \frac{clv^2}{d}$$

where l is the length of the pipe, v the velocity of the steam and d the diameter of the pipe. If Q represents the volume of steam flowing through the pipe per unit of time and A is the area of the pipe, then $Q = Av = \frac{\pi d^2 v}{4}$ but since $v = \frac{4Q}{\pi d^2}$, $h = \frac{16clQ^2}{\pi^2 d^4 d}$

and

$$Q = \frac{\pi}{4}\sqrt{\frac{d^5 h}{cl}}$$

The value of c depends on the condition of the pipe and on the diameter, but it is usually taken to be approximately equal to $\left(1 + \frac{3.6}{d}\right)$ and the formula becomes

$$Q = \frac{\pi}{4}\sqrt{\frac{d^5 h}{l\left(1 + \frac{3.6}{d}\right)}}$$

This formula may be converted to the more convenient form

$$W = 87\sqrt{\frac{Dhd^5}{l\left(1 + \frac{3.6}{d}\right)}}$$

in which W = weight of steam in pounds per minute
D = density of the steam in pounds per cubic foot
h = loss of pressure in pounds per square inch
d = diameter of pipe in inches
l = length of pipe in feet

Example 15. Calculate the weight of steam that may be conveyed for a distance of 300 ft. through a pipe 20 in. diameter with a loss of 1 lb. of pressure per sq. in. The absolute pressure of the steam is 160 lb. per sq. in and the density 0·357 lb. per cub. ft.

Solution.

$$W = 87\sqrt{\frac{0{\cdot}357 \times 1 \times 20^5}{300\left(1 + \frac{3{\cdot}6}{20}\right)}} = 87\sqrt{\frac{0{\cdot}357 \times 3{,}200{,}000}{300\left(\frac{20+3{\cdot}6}{20}\right)}}$$

$$= 87\sqrt{\frac{1{,}148{,}400}{354}} = 4{,}951 \text{ lb. per min}$$

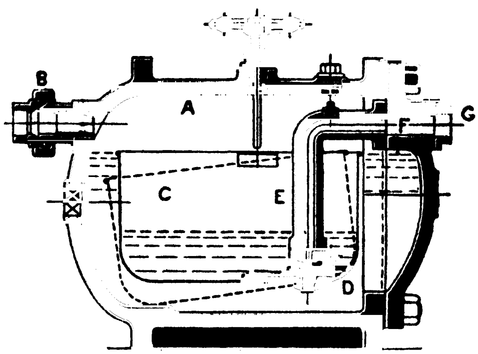


Fig. 26. Royles' Water Trap

It would be easy to make up a table to show what weight of steam could be conveyed for certain distances through pipes of different diameter with a reasonable loss of pressure.

Water Trap. This is a device which is attached to the steam pipe for the purpose of draining off the water formed by the condensation of the steam as it passes along the pipe. Fig. 26 shows the form of water trap made by Royles, Ltd., Manchester. It is seen to consist of casting having a removable cover secured in position by bolts. *A* is the body of the trap, *B* is the coupling by which the inlet pipe coming down from the steam main is joined to the trap, *C* is a cistern having a valve *D* attached to the bottom of it for the purpose of opening or closing the lower end of the outlet pipe *E*. *F* is the

outlet, and *G* is the joint to which the drain pipe is attached. If we consider that the cistern *C* is empty in the first instance, and that water of condensation enters by the pipe *B*, it is apparent that the cistern will float on the water in the trap, thus closing the valve *D*, but the water continues to rise until it overflows into the cistern. When the cistern has become filled to the top it sinks, and in sinking the valve *D* is opened

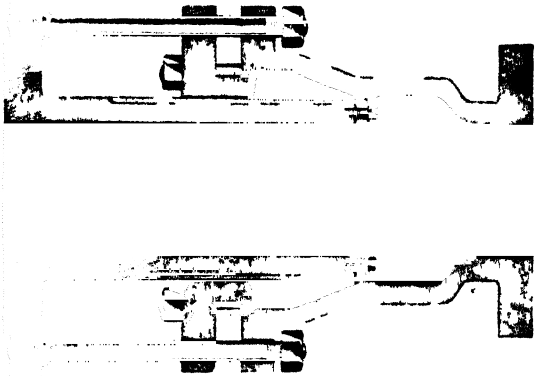


FIG. 27. HOPKINSON COMPOSITE EXPANSION JOINT

and the water in the cistern is ejected from the trap under the pressure of the steam in the main. The cistern again floats, and in rising closes the valve *D*, the height through which the cistern can rise being determined by the adjustment of the spindle shown in the figure. The use of such a trap prevents the water of condensation being carried to the steam engines and possibly collecting in the cylinders of such engines with the risk of serious accident on the resumption of operations.

Expansion Joints. Steam pipes must always be arranged so that they are free to expand longitudinally due to the changes in their temperature. Occasionally it is desirable to anchor them at certain points so that the expansion takes place in a predetermined direction, where provision is made for any movement that may occur. If the piping lay-out has a number

of bends throughout its course there may be no need of expansion joints, but in long, straight ranges of steam pipes some form of expansion joint or expansion bend will be necessary. It is usual to recommend that high-pressure steam pipes should have provision for expansion every 40 to 60 ft. of straight run, and from 80 to 100 ft. when low-pressure steam is used. The greater the provision made for expansion the greater will

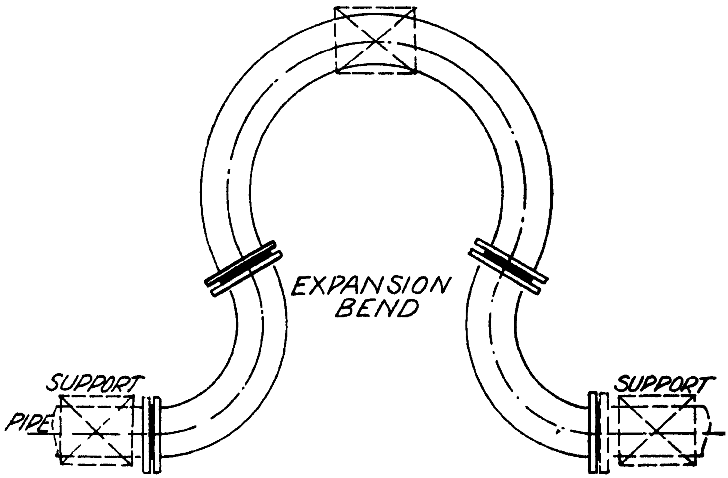


FIG. 28 THREE-PIECE EXPANSION BEND

be the durability of the jointing material at the flanges. Fig. 27 shows a sectional view of the bayonet pattern of expansion joint. The Hopkinson composite joint is made of cast-iron or cast-steel and has bronze sliding parts.

In the steam main conveying steam at 115 lb. per sq. in. absolute from the surface to a pump at a depth of 300 yd. at Neilsland Colliery, Hamilton, one expansion piece of this form was installed at the top of the upcast shaft on the outside of the housing, where the packing of the stuffing box could be attended to and no steam could escape into the shaft. The joint was efficient and was capable of giving an extension of 20 in. When the variation of temperature is $T°$ F., and the

depth of the shaft is represented by D, the coefficient of linear expansion being C, the length of the expansion piece must at least be that given by the product CDL. Fig 28 shows the three-piece expansion bend commonly used when the bore of the steam main exceeds 8 in It may be erected in the vertical position or it may be supported in the horizontal position upon three pillars placed one at each end of the piece and the other at the middle of the bend. A common form of support consists of a pillar of brickwork upon which is laid an iron plate, so that a short circular rod of iron may be used as a roller for the steam pipe to roll upon The support may also be made of wood or iron or steel.

Lagging of Steam Pipes. Steam pipes should always be covered with non-conducting material to a depth of at least 2 in to prevent loss of heat by radiation, and consequent condensation of some of the steam When superheated steam is used the pipes should first be covered with about ½ in of asbestos composition, after which the pulp ordinarily used is applied. The plastic covering is applied when the pipes are hot, and it may be reinforced if subject to vibration

REFERENCE BOOKS

Steam and Other Engines, by Duncan.

A Text book of Heat Engines, by Jamieson and Andrews.

Motive Power Engineering for Engineering and Mining Students, by Harris

EXERCISE QUESTIONS

1. Show by sketches how you would connect the individual boilers of a range to the common feed water main What are the various means of heating feed-water?

(*2nd Class Exam*, Oct, 1921)

2. In conducting steam through a long range of pipes, what precautions would you take to get the best efficiency at the engine using the steam, and reduce the risk of breakdowns?

(*2nd Class Exam*, Oct, 1921)

3. Describe a gauge glass and fittings for showing the level of the water in a boiler. If you suddenly noticed that no water was showing in the gauge glass of a Lancashire boiler under steam, what would you do? (*2nd Class Exam*, May, 1918.

4. In order to complete a pipe range a straight length of cast iron flanged pipe is wanted, 9 ft long over flanges and 6 in.

internal diameter, with one flanged branch 6 in. diameter at 2 ft. 6 in. from one end The distance from the centre of the pipe to the face of the flange on the branch is to be 9 in. All flanges are to be 12 in in diameter by 1 in. thick. The metal of the body of the pipe is to be ⅞ in. thick

Make a drawing of the pipe to a scale of ½ in. to the foot, showing all dimensions required for making the pipe.

5. Describe with sketches how you would erect a steel chimney, 5 ft. in diameter by 50 ft. high, made of plates ¼ in. thick. The complete chimney is lying on the ground to start with and must be placed on a brickwork base, 4 ft. high, prepared for it

(1st *Class Exam.*, May, 1919)

6. In connection with a new colliery being laid out on a large scale and needing underground power for pumping and hauling, describe the measures to be taken to economize in the consumption of coal. (1st *Class Exam*, May, 1918)

7. Describe the construction of a dead-weight safety valve, and state the precautions you would take to ensure that steam would blow off at the desired pressure.

8. Describe the construction and action of a pressure-reducing valve, and state the circumstances in which such a valve might be used at a colliery.

9. Sketch and describe the Hopkinson-Ferranti steam stop valve, and state the principle upon which its construction is based.

10 An expansion joint is to be connected to a line of screw-jointed malleable iron pipes, 300 ft. long, conveying steam at a temperature of 305° F. Describe alternative forms of expansion joint and calculate the amount of expansion to be allowed for when the pipes cool to 50° F.

11 Describe two methods of causing the draught necessary for the combustion of bituminous slack in the furnace of a Lancashire boiler, and state the possible disadvantage of the use of the steam jet for that purpose.

12. Describe the construction and action of a Green economizer, and draw a plan to show the position of the economizer relative to the boilers to which it is connected, and the arrangement by which the hot gases are conducted direct to the chimney without passing through the economizer. What is the advantage of an economizer?

13. Describe a superheater as applied to a water-tube boiler or to a Lancashire boiler What is the object of superheating steam? What provisions are necessary in the construction and operation of an engine to enable it to use superheated steam?

(1st *Class Exam*, Nov, 1922.)

CHAPTER IV

STEAM-ENGINES AND AUXILIARY PLANT

THE steam-engines used at collieries may be of the vertical or horizontal type, with one, two, or even three cylinders. The small engine used to drive the screening plant may have but one cylinder, and the engine used to drive the fan may be of similar simple construction, if small, but if the power required for ventilation is high the fan engine may have two cylinders arranged in tandem, the steam being used expansively in both. Haulage engines may be of similar construction, or they may be cross-coupled, like pumping and winding engines, the steam being used expansively and condensed, or exhausted to the atmosphere or to a steam accumulator.

Compound engines are used in order that economy may be effected in the use of steam, but should it be necessary to generate electricity or compress air for transmission to remote parts of mines the engines on the surface may be designed to exhaust steam into a steam accumulator for the supply of steam to turbo-generators. There are, therefore, two distinct methods of economizing in the use of steam, and that method used in a particular case is determined mainly by the method employed to transmit power to underground machinery and the type of winder used.

Coal Consumption. The utility of the various types of engines may be compared on the basis of coal consumption per indicated horse-power per hour. The following figures are typical—

For	non-condensing engines	3 to $5\frac{1}{2}$ lb per i h p hr
,,	condensing engines	2·5 to 3 ,,
,,	compound non condensing engines	2·5 to 3 ,,
,,	compound condensing engines	1·6 to 2·5 ,,
,,	triple-expansion condensing engines	1·5 to 1·75 ,,
,,	steam turbines	1·5 to 1·65 ,,

Principal Parts of a Simple Steam-engine. A steam-engine, as the term is ordinarily understood, is one in which the

reciprocating motion of a *piston* is translated to rotary motion of a *crankshaft*. The pressure of the steam exerted on the piston is communicated to the *piston rod* and *crosshead* running in *parallel-bar or trunk guides*.

The force communicated to the crosshead is transmitted by the *connecting rod* to the *crank pin*, and as the path of the crank pin is circular the moment of the force in the connecting rod about the crankshaft centre is utilized to produce rotation of the crankshaft, and any pulley, drum, or wheel that may be attached to it. The reciprocating motion of the piston is produced by admitting steam alternately to the *steam ports* which connect the *valve chest* with the ends of the *cylinder*, and as the torque applied to the crankshaft is necessarily a varying one a *flywheel* is attached to the crankshaft to minimize the fluctuations of speed. The distribution of steam to the steam ports and the passage of steam from the cylinder to the *exhaust port* is effected by means of a *slide valve*, and the amount of steam supplied to the engine is regulated by a *throttle valve*. Since the load on an engine may vary irregularly it is desirable that the supply of steam should be regulated automatically in accordance with the load. This is done by a *governor*, which is driven by a belt from the crankshaft, and operates on the throttle valve or a *butterfly valve* in the steam main. The slide valve is operated by some form of *link gear* which is designed to enable the direction of rotation of the engine to be reversed. Such gear is usually actuated by *eccentric pulleys* on the crankshaft, and the latter rotates in the bushed bearings of the *pedestals* attached to the *bedplate* of the engine, all bearings being lubricated by oil contained in suitable *lubricators*.

Construction of Cylinder. Fig. 29 shows in section the cylinder of a steam-engine in which the distribution of steam is to be effected by an ordinary *D* slide valve. The cylinder, the cylinder covers and the steam chest are made of grey cast-iron, and there are two steam ports connecting the cylinder with the steam chest in addition to one exhaust port which connects the steam chest with the exhaust pipe. The

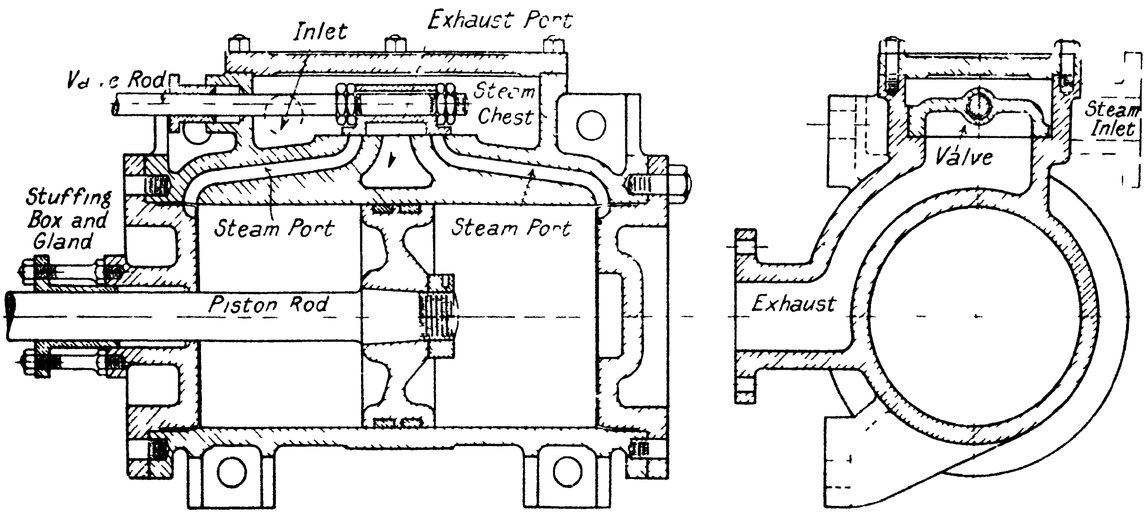


FIG 29 CYLINDER OF STEAM ENGINE

steam chest is cast in one piece with the cylinder, and is provided with a cast iron cover that is secured in position by bolts. The distribution of steam supplied to the engine is effected by means of the slide valve, which is actuated by the rod. The cylinder and valve chest are made steam-tight by the use of suitable packing material held in position in the stuffing boxes by means of glands held in position by studs and nuts. The interior and ends of the cylinder are turned in the lathe, and the valve seat is reduced to a smooth surface in the planing machine. Holes are bored and tapped to receive lubricators, indicator cocks and drain cocks.

Piston. The pistons of small engines are usually made of cast iron, whereas the pistons of large engines are made of forged steel or cast steel. Fig. 29 shows a cast-iron piston which is made steam tight by having spring rings fitted into grooves turned out of the contact surface of the piston. These rings are made of cast iron, and are cut as required from a hollow cylinder of the requisite thickness and diameter, and they are cut in one place to enable them to be sprung into position on the piston. When the piston is placed in the cylinder and the steam is admitted to one side of the piston, the pressure of the steam tends to cause leakage of steam to the other side of the piston, but that is prevented by the resilience of the rings which press firmly against the wall of the cylinder.

Piston Rod. Several methods are used for attaching pistons to piston rods. The piston rod may be tapered at 1 in 6 on the diameter and the piston secured to it by riveting, but it is much more convenient to secure the piston to the piston rod by means of a nut and lock nut, or by a nut held firmly in position by a split pin passing through the nut and the piston rod. Having regard to the alternating stresses applied to a piston rod it is important that that part of the engine should be made of mild steel and that it should not be subjected to stresses exceeding 5000 lb. per sq. in. In order that the stress should be limited to that specified, the diameter of

the piston rod should be proportioned to the diameter of the cylinder, as provided for in the equation—

$$\frac{\pi}{4} D^2 P = \frac{\pi}{4} d^2 f$$

where D is the diameter of the cylinder in inches, d the diameter of the piston rod in inches, P the maximum effective pressure of the steam in pounds per sq. in., and f the safe stress in the material of the rod. When f equals 5000 the above expression reduces to $d = \frac{D\sqrt{P}}{70}$.

Example 16. A steam engine has a cylinder 24 in. in diameter and it is supplied with steam at 100 lb. per sq. in. by gauge. Calculate the minimum diameter of the piston rod.

Solution.

$$d = \frac{24 \times \sqrt{100}}{70} = \frac{240}{70} = 3.43 \text{ in.}$$

Stuffing Box and Gland. The positions of two stuffing boxes and glands are shown in Fig. 29, one for the piston rod, the other for the valve rod. In the case of the former the stuffing box is cast in one piece with the front cylinder cover and a hole is bored out a working fit at the centre of the cover, the stuffing box being turned in the lathe to a diameter suitable for the reception of the packing material, which may consist of rope, asbestos or metallic packing. The inner surface of the gland is turned to fit the piston rod and the outer surface to fit the stuffing box, and the gland is held in position by studs and nuts. The packing is pressed against the walls of the stuffing box and the piston rod by screwing down the nuts, one after the other, around the gland. The valve rod stuffing box is cast with the steam chest and the gland is secured to the stuffing box by studs and nuts.

Crosshead and Guides. That part of the engine by which the piston rod and connecting rod are connected is called the crosshead, and in the case of small engines the crosshead is fitted at the ends with slippers that run between parallel

guide bars fitted to the bedplate of the engine, but in the case of large winding, fan, or compressor engines, the piston rods are attached to large blocks that slide within circular trunk guides. *The forked ends of the connecting* rods are connected to the blocks by means of gudgeons. The bearing surfaces of either form of slipper are designed to limit the bearing pressure to about 50 lb. per sq. in., and gutters are cut in the surfaces to facilitate the lubrication of the sliding surfaces. Siphon lubricators are used generally.

Connecting Rod. As a general rule, the length of a connecting rod should not be less than 2½ times the stroke of

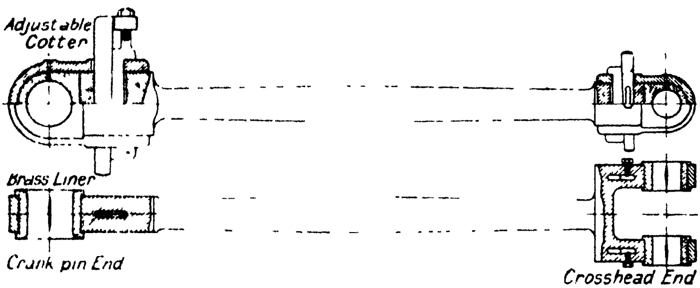


FIG. 30 CONNECTING ROD

the engine. This is found necessary to limit the bearing pressure of the crosshead slippers on the guides. Owing to the alternating stresses applied to a connecting rod, it is necessary that it should be made of steel, and because of the tendency to buckling and bending, especially in the case of large engines, it is usual to turn connecting rods so that the diameter is greater at the middle than at the ends, the proportion being about 1·4 to 1. The connecting rod is usually attached rigidly to the crosshead pin, but, as is shown in Fig. 30, it is provided with bushes at the crank-pin end. These bushes are adjustable and are held in position by a cotter and pin. Brass bushes are provided, and as these wear the position of the cotter may be adjusted, and the diametral surfaces of the bushes may be planed, so that the bearing may not be allowed to work loose.

Crank and Crankshaft. The cranks of small engines may be made of cast-iron or cast-steel, but large engines are usually fitted with cranks of mild steel that have been forged to shape. Fig. 31 shows a forged crank and the method by which it may be fitted to the crankshaft and crank pin. The crank and crankshaft may be turned to gauge so that the crank fits the crankshaft, and the fixture is made by driving tapered

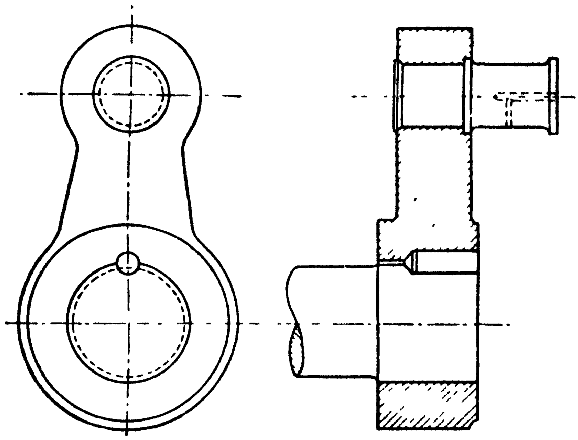


FIG. 31 FORGED CRANK WITH SHAFT AND PIN

keys into keyways cut partly in the shaft and partly in the crank. The illustration shows a circular key which is driven into a round keyway, which is bored after the crank has been sweated in position. The crank is heated sufficiently to allow the shaft to be pushed into position, and on cooling the crank shrinks and grips the shaft firmly. Further security is obtained by the round key. The crank pin may be fitted in the same way, but it is usual to rivet the pin after sweating in position. The sketch shows holes bored in the crank pin for the purpose of lubrication. The cranks of smaller engines and pumps are sometimes made by bending to form cranks and crankshaft from one piece of metal. The main bearings upon which a crankshaft is carried are substantially made and are provided with renewable anti-friction liners and siphon lubricators,

and the whole of the engine is mounted on a soleplate of cast-iron that is bolted to the foundations.

Eccentric Sheaves and Straps. Fig. 32 shows a pair of sheaves attached to a crankshaft eccentrically, and the sheaves are surrounded by straps, which are connected by two rods to the opposite ends of a circular slot-link at the points *A* and *B*. The curved link is attached at the point *C* by another link of simple form to one end of a lever *L* that turns about a shaft at *F*. The end of the valve rod is attached to a block

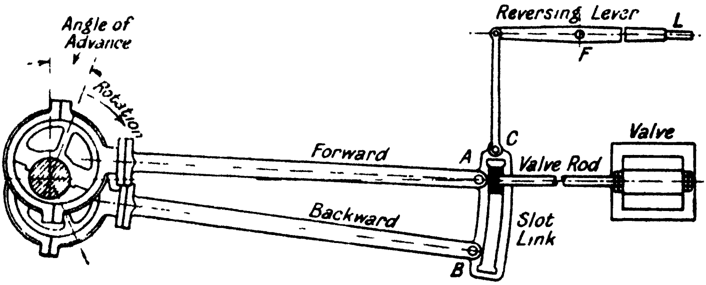


FIG. 32. STEPHENSON LINK GEAR

fitted between the sides of the curved link, and it is easy to see that as the crankshaft rotates the valve rod will be caused to reciprocate by the eccentric operating the rod attached to the curved link at *A*, and it will be realized that if the engine is at rest and the link is raised so that the end *B* of the other connecting rod takes up the position formerly occupied by *A*, the valve rod will be operated by the eccentric to which *B* is connected. The arrangement described is Stephenson's link gear, and it is used to operate the steam valves of reciprocating engines, enabling the engines to be reversed by the simple act of raising or lowering the lever *L*.

Slide Valve and its Action. Fig. 29 shows the form of the ordinary *D* slide valve and the method by which it is secured to the valve rod. The valve is shown in its mid-position, and it is seen that not only are both of the steam ports covered, but that the valve overlaps the ports. The amount of overlap

is called *outside lap* and *inside lap*, the former term applying to the amount of overlap from the outer edge of the steam port to the corresponding edge of the valve, and the latter to the projection of the inner edge of the valve beyond the inner edge of the steam port. The *travel* of the valve is distance travelled from one extreme position to the other, and it is equal to twice the amount of eccentricity between the crank and eccentric sheave centres, i.e. twice the throw of the eccentric. As it is generally desirable that the valve should open before the piston arrives at the end of the stroke, the eccentric operating the valve is advanced beyond the position of being at right angles to the crank when that is in either of the dead points. The amount of opening is called the *lead*, and the *angle of advance* is the angle between the centre line of the eccentric and a line at right angles to the crank. It will be readily understood that if the valve is operated by the eccentric the angle between the crank and the centre line of the eccentric is always 90° + angle of advance, and the eccentrics of a reversible engine must both be placed in that position with respect to the crank.

Referring to Fig. 29, it will be seen that when the valve has uncovered the left-hand port of the engine the piston will be caused to move towards the right, but before the stroke has been completed the valve will have commenced to move to the left, and having admitted some steam the motion of the piston will be arrested by the cushion of steam thus provided. When the stroke has been completed the full pressure of the steam is admitted to the right hand side of the piston, and the piston is propelled forward under that pressure until the valve returns and cuts off the entry of steam, the remainder of the stroke being executed by the expansion of the steam already in the cylinder. The valve is proportioned so that the expanded steam is exhausted a little before the completion of the stroke to render effective the cushion of steam on the other side of the piston. There is thus a cycle of events aptly described as admission, expansion, exhaustion and compression, and occurring in the order given.

Zeuner Valve Diagram. The distribution of steam and the relative positions of valve and crank can be determined easily by means of a Zeuner diagram like that shown in Fig. 33.

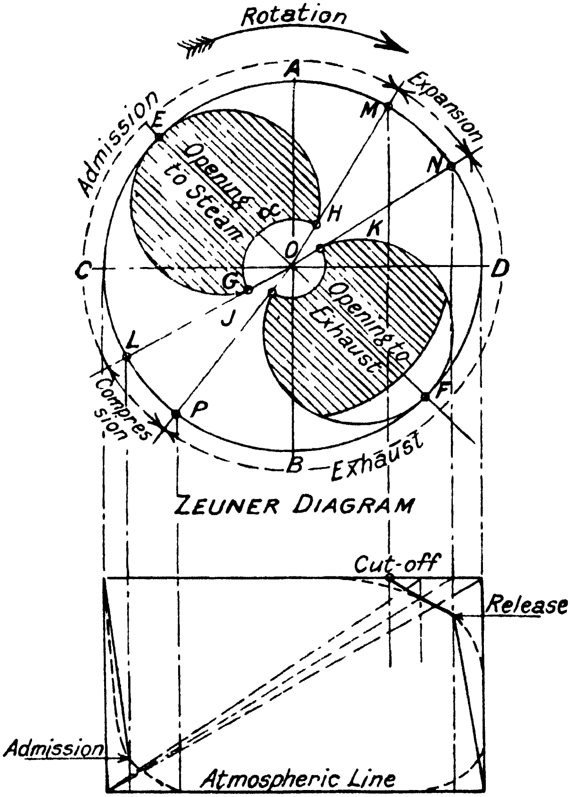
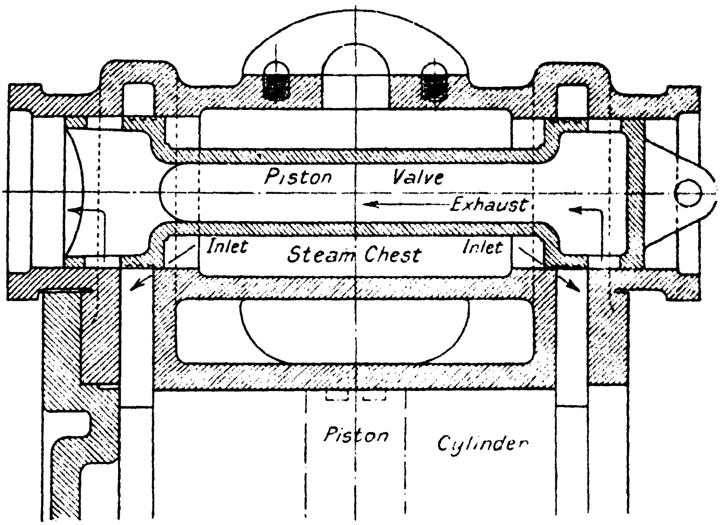


FIG. 33. ZEUNER DIAGRAM

Draw a circle $ACBD$, having a radius equal to half the travel of the valve, the lines AB and CD being at right angles and intersecting at the point O. Mark off the angle α equal to the angle of advance, and draw the line EOF. Construct the circles having OE and OF as diameters, then with centre O

and the outside lap as radius describe the arc *GH*. Also, with *O* as centre and inside lap as radius, describe the arc *JK*. Draw the lines *OG*, *OH*, *OK*, and *OJ* and produce them to intersect the outer circle at the points *L*, *M*, *N*, and *P*. The points have been projected downwards to enable a hypothetical diagram of the steam distribution to be drawn. Since



(Messrs Walker Bros., Pagefield Ironworks)

FIG. 34. PISTON VALVE

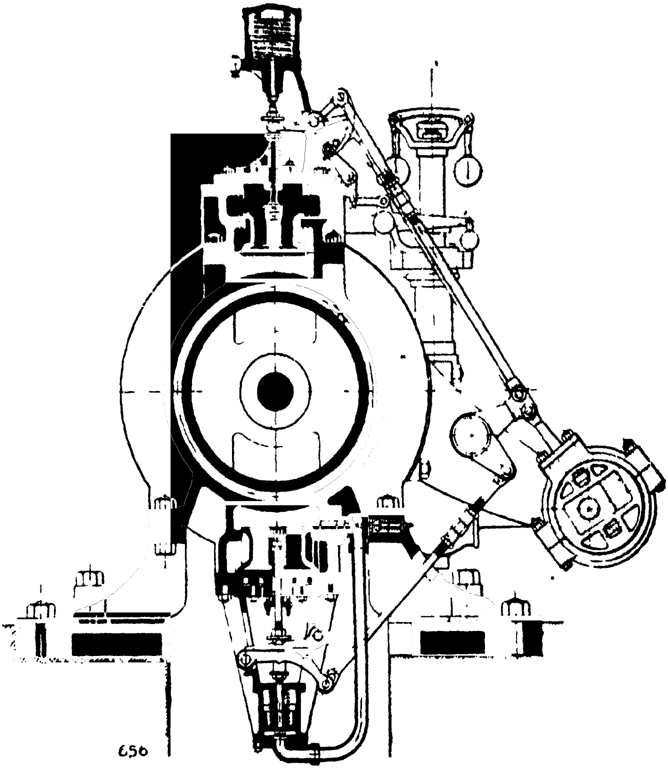
ordinates are pressures to scale and the length of the diagram is a scalar representation of the length of the cylinder, the diagram is a diagram of work.

Piston Valve. Fig. 34 shows a section of a piston valve such as is fitted to the haulage engine shown in Fig. 140. It is seen that the valve is placed in a cylindrical steam chest, that it is fitted with rings at both ends, that the steam ports are situate near the ends of the piston, and that the piston is hollow and closed at the end by which the attachment is made to the piston rod. The piston valve is used in large

engines, e.g. the Worsley Mesnes winding engines at Gwaun-cae-Gurwen Colliery, Steer Pit, but they may be fitted to smaller engines designed to be driven either by steam or compressed air. A study of the illustration shows that when the valve is moved towards the right the steam or air passes from the chest through the steam port to the cylinder, thus causing the piston to move to the left. Meanwhile the left-hand port is uncovered, and the working stuff is exhausted to the atmosphere. The movement of the piston valve towards the left admits steam or air to the cylinder to cause the piston to move towards the right, and it will be seen that the exhaust steam or air will this time pass through the interior of the valve to be exhausted at the left-hand end of valve casing. Free exhaust enables the ice formed in the exhaust port of a compressed air engine to be dealt with at once, but in the interest of safety an exhaust pipe would have to be attached to the casing when steam is the working stuff. It is worthy of note that the valve shown in the illustration has no steam or outside lap, but has ¼ in. of inside or exhaust lap

Hackworth Valve Gear. On referring to Fig. 140 it will be seen that the valve rod is attached to a link which is connected at one end to a slipper working in a slide and at the other end to the crank pin. As the crank pin rotates the valve rod is actuated, and when it is necessary to reverse the direction of rotation the valve is positioned by the reversal of the lever, which is seen to be attached to the shaft upon which the slides are mounted. The Hackworth gear is the parent of all radial gears, and is at once the simplest and most compact of the gears used in the construction of engines for mining auxiliary services

Trip Valve Gear. Winding engines fitted with the ordinary slide valve are notoriously wasteful of steam, and while the economical use of steam may not be of great importance when engines are comparatively small, the matter does assume great importance when a large amount of steam is required for winding purposes. Trip gears are fitted to large steam



(Robey & Co.)

FIG. 35 TRIP VALVE GEAR

winders with the object of providing an earlier cut-off as the winding progresses. On referring to Fig. 35, which shows the form of valve gear fitted to winding engines by Messrs. Robey & Co., Lincoln, it will be seen that the steam valve is placed above the cylinder, and that the exhaust valve is placed below it. There are two steam valves to each cylinder and two exhaust valves, both sets being operated by a system of levers from eccentrics mounted on a lay shaft running at right angle to the crankshaft. Each steam and exhaust valve is actuated by one eccentric, and the manner in which the valves are operated can be followed in studying the illustration. A governor of the pendulum type is fitted to actuate the trip mechanism, and it is operated by gearing from the lay shaft. The eccentric in turning about the lay shaft pulls down the main rod and with it the curved tripper, which depresses the valve-lifting lever by means of a hard steel tripping plate. Mounted alongside each main eccentric is the expansion eccentric shown in Fig. 36. This eccentric is at the top of its stroke when the main eccentric is in the position at which the valve commences to open, and as the movement continues it descends and pulls down the rod connected to it by depressing a roller on the curved tripper. With the governor in its lowest position, this roller never engages long enough with the curved lever to trip, but as the speed of rotation increases the trip shaft is turned and the lever and links bring the roller nearer the curved lever, and it disengages the tripper from the valve lever as this is returning to its upper position. At the highest speed of the crankshaft the tripper is prevented by the roller from engaging with the valve rod and the valve remains closed. The valve opening at intermediate speeds is conditioned by the position of the roller. The obvious advantage of such a method of operating valve gears is that steam is admitted to the cylinders as it is necessary, and the expansive property of steam is used to the fullest extent. When the tripping gear operates the steam valves are immediately closed by the dash-pot springs. Reversal of the engines is obtained by the shifting of the eccentrics in the lay shafts

by means of the sliding sleeve and lever seen projecting from the floor in Fig. 36.

Corliss Valve Gear. Fig. 37 shows a half sectional elevation of an engine cylinder which has Corliss valves fitted to connect

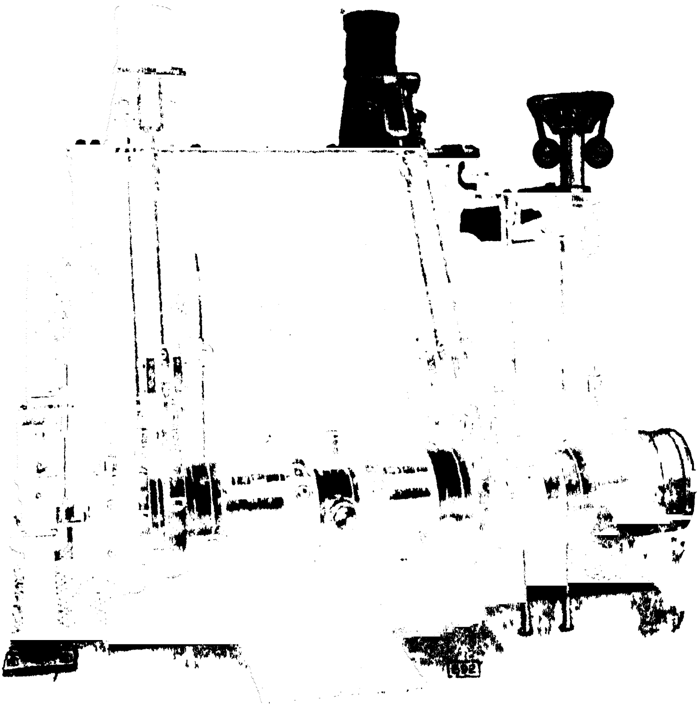


FIG. 36. TRIP VALVE GEAR: GENERAL VIEW

the steam and exhaust ports with the cylinder. The valves are cylindrical slides that are rotated by rods from a wrist-plate pivoted on the side of the cylinder next the tripping mechanism. The steam enters at *E* and is exhausted at *F*, the admission of steam being controlled by tripping gear of

the Dobson variable type. It is easy to see that the clearance space necessary for such valves is a minimum, and that by the great length of the valve the port opening is great, hence the valve is effective in passing large volumes of steam with small movement operated by simple valve mechanism.

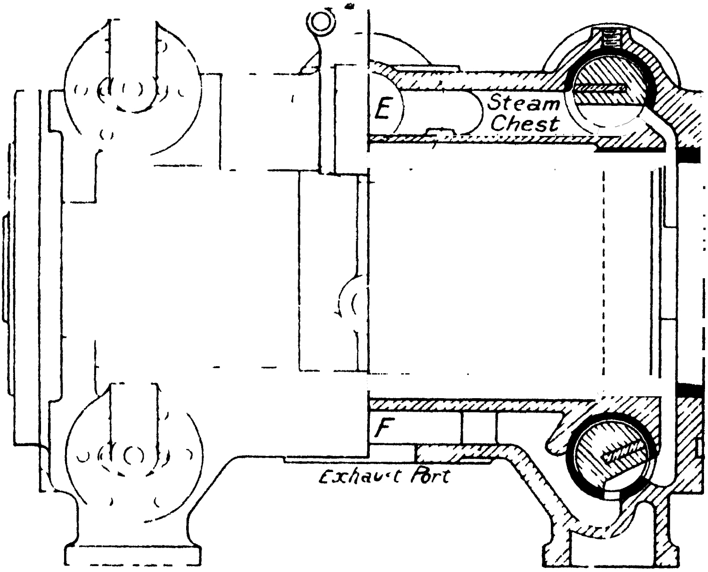


FIG. 3. CORLISS VALVE ENGINE.

Corliss gear is used to effect economy in steam consumption on large fan winding and compressor engines.

Indicator Diagram of Work. James Watt devised a means of reproducing pictorially the changes which take place in the pressure of steam as the piston moves along the cylinder. He designed a small auxiliary cylinder which was fitted with a piston, operated by steam from the main engine cylinder, and which had a pencil attached to the piston rod. As the pressure of the steam in the engine varied, the piston carrying the pencil was pushed upwards against the spring, or was lowered under the action of the spring. While the pencil moved vertically a sheet of paper mounted on a suitable

board, was moved backward and forward across the pencil by means of a cord attached to the cross head of the engine

The curve drawn on the paper represented the variations in the pressure of the steam during two strokes of the engine on that side of the piston to which the indicator was attached

The area enclosed by the diagram divided by the length gives the average height of the diagram, and therefore the mean pressure of the steam

When steam is admitted to the cylinder of an engine the pressure behind the piston rises almost at once to the full

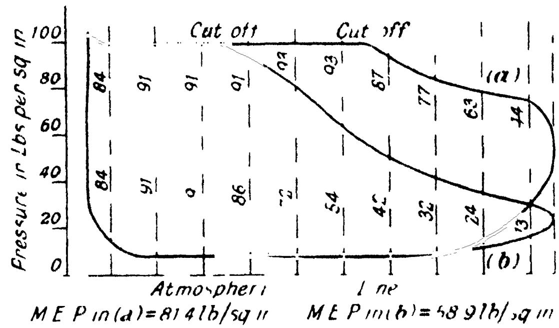


FIG 38 INDICATOR DIAGRAMS FROM WINDING ENGINE

pressure (unless the ports of the engine are of inadequate cross section) and the piston moves forward under the constant pressure of the steam until the steam is cut off after which it completes the stroke under the varying or diminishing pressure of the steam as the steam expands On the return stroke the steam is expelled from the cylinder to the atmosphere or to a condenser as the case may be If the steam is discharged to the atmosphere the line traced out by the indicator during the return stroke will be just a little above the atmospheric line, whereas the exhaust pressure line would be nearer to the zero line where the steam is discharged into a condenser

Fig 38 (*a*) shows an indicator diagram taken from a winding

engine during the acceleration period, and Fig. 38 (*b*) shows the effect of the trip gear when acceleration has been completed and the trip gear has come into operation. The effect of the tripping mechanism on the variations of steam pressure may be observed during a complete winding operation by a continuous indicator diagram. If the indicator diagram of a continuous running engine is taken for front and back strokes the average horse-power may be calculated, but it is first necessary to find the mean effective pressure of the steam. That may be done by finding the area of the diagram by means of a planimeter and dividing the area by the length, or it may be found by taking the mean of the sum of the mid ordinates. When that has been obtained the horse-power of the engine may be calculated The following are the steps

1 The area of the piston $\frac{\pi}{4}d^2$ sq in.

2 The total pressure of the steam $\frac{\pi}{4}d^2 \times P_m$ lb

3 The work done per stroke $\frac{\pi}{4}d^2 P_m L$ ft.-lb.

4 The work done per revolution $= \frac{\pi}{4}d^2P_m \times 2L$ ft -lb

5 The work done per minute $= 2 \times \frac{\pi}{4}d^2P_m LN$ ft -lb.

6. The horse-power $= 2 \times \frac{\pi}{4}d^2P_m LN \div 33{,}000$

When there are two cylinders the horse-power will be twice that developed in one cylinder

Brake Horse-power. The indicated horse-power of a steam-engine is that developed in the cylinder of the engine, but the amount of power given out at the crankshaft of the engine is necessarily a fraction of the indicated horse-power, and the ratio of the output horse-power to the input horse-power is an expression of the mechanical efficiency of the engine. The output horse-power is ascertained by means of a brake test

just as the input horse-power is determined from indicator diagrams, hence

$$\text{Mechanical efficiency of an engine} = \frac{\text{brake horse-power}}{\text{indicated horse-power}}$$

The brake horse-power is ascertained by a brake test, and Fig. 39 shows the arrangement of a rope dynamometer as

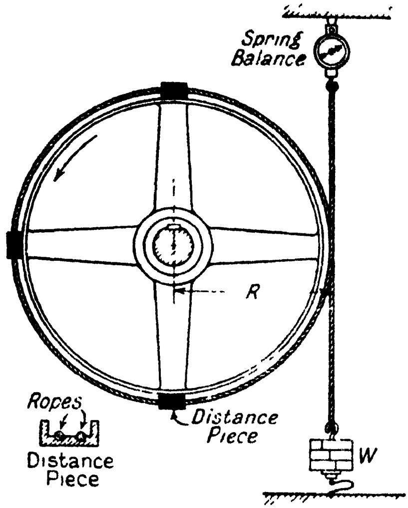


FIG. 39 ROPE DYNAMOMETER

used for making such tests on steam and other engines. As indicated in the illustration, two ropes are attached to couplings at their ends, and they are passed around a pulley or flywheel to completely encircle it.

To prevent the ropes slipping from the pulley a number of distance pieces of wood, shaped as in the enlarged section, are attached to them.

One end of the ropes is attached to a Salter spring balance suspended from a beam above the wheel, the other end being attached to the weight *W*. The ropes should be lubricated with castor oil or grease before being put into use, especially when the tests are to run for a considerable period of time.

The size of manila rope used depends largely on the power

of the engine and the peripheral speed of the engine. In testing engines from 100-150 b.h.p. with speeds up to 4000 ft. per min., a rope one inch diameter will be found quite satisfactory. When there is a possibility of a large amount of heat being produced, in consequence of which the temperature of the flywheel would be likely to rise considerably, the flywheel should have a channel section, or an internal groove, in which water would be made to circulate during the test. Cold water would be conveyed to the wheel at one side, and in passing round would be "scooped" from the groove at or near the bottom of the wheel.

In testing the engine with this apparatus the engine is started and weights are added to W, the speed being regulated by the admission of steam to the cylinder or current to the motor. When the desired speed has been obtained the reading of the spring balance is taken and the suspended weight is noted.

It will be observed that the wheel tends to raise W, and consequently the torque will be WR lb.-ft.

The torque due to the pull in the spring acts with the wheel, and is wR, therefore the net torque on the shaft is $R\,(W - w)$ lb.-ft., and the b.h.p. $= \dfrac{2\pi\,R(W - w)\,N}{33{,}000}$.

Example 17. A steam engine was indicated when running at 120 revolutions per minute, and it was found that the indicated horse power was 50. During the indicator test a brake that was made and the reading of the spring balance was 20 lb., while the weight suspended from the rope was 250 lb. Given that the radius of the brake pulley was 8 ft., find the mechanical efficiency of the engine.

Solution.

$$\text{Mechanical efficiency of engine} = \frac{\text{brake horse-power}}{\text{indicated horse-power}}$$

$$= \frac{2\pi R\,(W - w)N}{33{,}000 \times \text{i.h.p.}}$$

$$= \frac{2 \times 22 \times 8\,(250 - 20)\,120}{7 \times 33{,}000 \times 50}$$

$$= 0{\cdot}83, \text{ or } 83 \text{ per cent}$$

Fly-wheel. The function of a fly-wheel is to balance the

variations of torque arising from the continually altering relative positions of the piston rod, connecting-rod, and crank in a steam-engine, or to balance peak loads on electrical machinery. The maximum torque of a steam-engine is obtained at the instant the connecting rod is at right angles to the crank, and the torque is least when the piston, connecting-rod, and crank are in alignment. As the former position is approached energy is imparted to the fly-wheel, and as the latter position is approached the fly-wheel gives up energy to the crankshaft to make up for the diminishing turning effort of the crank, and consequently the speed of rotation falls slightly according to the weight of the wheel. If we suppose that a fly-wheel has a mass m lb. and a mean radius of r ft., we may calculate the variation of speed corresponding to a certain fluctuation of energy as the velocity of a point at the mean radius changes from v_1 to v_2 ft. per second, thus

$$\text{Kinetic energy, } K_1 = \frac{m v_1^2}{2g} \text{ ft.-lb. and}$$

$$\text{Kinetic energy, } K_2 = \frac{m v_2^2}{2g} \text{ ft.-lb.}$$

If v_1 is greater than v_2 the speed of the fly-wheel will diminish and the loss of kinetic energy will be $W = K_1 - K_2$ ft.-lb.,

$$\text{hence } W = K_1 - K_2 = \frac{m v_1^2}{2g} - \frac{m v_2^2}{2g}$$

$$= \frac{m}{2g}(v_1^2 - v_2^2) \text{ and } v_1^2 - v_2^2 = \frac{2gW}{m}$$

Example 18. What must be the weight of a fly-wheel having a mean radius of 3 ft., if the speed falls from 150 revolutions per minute to 147 while the wheel gives up 5000 ft.-lb. of energy per sec. to the shaft.

Solution.

$$v_1^2 = \left(\frac{2\pi R N_1}{60}\right)^2 = \left(\frac{2 \times 22 \times 3 \times 150}{7 \times 60}\right)^2 = 2222 \cdot 4$$

$$v_2^2 = \left(\frac{2\pi R N_2}{60}\right)^2 = \left(\frac{2 \times 22 \times 3 \times 147}{7 \times 60}\right)^2 = 2134 \cdot 4, \text{ and}$$

$$m = \frac{2gW}{v_1^2 - v_2^2} = \frac{2 \times 32 \cdot 2 \times 5000}{88} = 3659 \text{ lb.}$$

Governors. If the throttle opening of a steam-engine is fixed, the speed varies inversely as the load, and if it is desired that the speed of the engine should be steady, it is usual to govern the throttle opening by means of a governor. Fig. 40

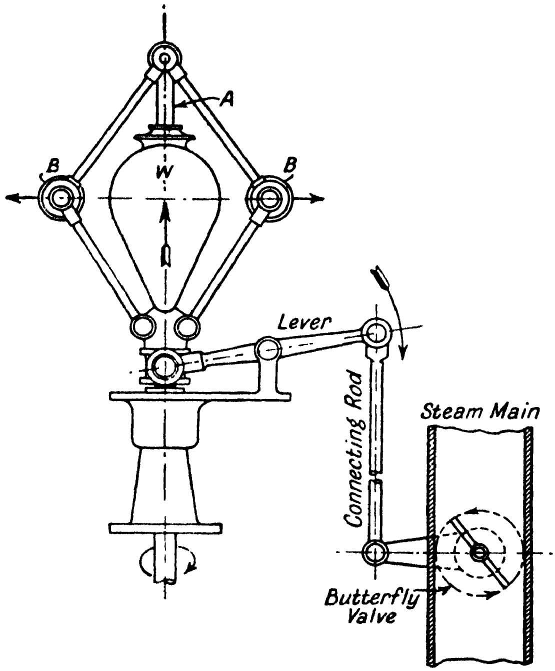


FIG. 40. WATT PENDULUM GOVERNOR

represents the form and arrangement of the Watt pendulum governor.

The vertical spindle A is driven through belt and bevelled gearing from the crankshaft, and as the spindle rotates it carries with it the weight surrounding it and the other two balls which are connected by rods to the top of the spindle and the bottom of the central weight W. When the speed is steady the centrifugal forces in the balls B balance their own weights and that of the central weight in addition to

the connecting rods, but should the speed increase the balls fly outwards and raise the central weight, thus acting on the lever by which the butterfly valve in the steam pipe is adjusted. Since the supply of steam to the engine is lessened, the speed diminishes, and the balls fall back to their normal position corresponding to the load on the engine. The governing of the engine by throttling the steam results in the alteration of the pressure of the steam entering the cylinder. Sometimes the central weight is replaced by a steel spiral spring, as in the case of the Hartnell governor, and as the force in the spring is capable of adjustment the governor may be made sensitive to small variations of speed. A too sensitive governor may cause the engine to *hunt* due to marked variations of steam pressure.

Condensers. We have already seen that economy may be effected in the use of coal by discharging steam from a non-condensing engine into a feed-water heater, but if the steam is discharged into a condenser where a partial vacuum is maintained a corresponding saving of fuel is effected by establishment of a greater balance of pressure between the opposite sides of the pistons of the engines using steam. If a mercury gauge attached to the condenser shows an unbalanced column of 26 in. of mercury, it signifies that the back pressure of steam on the piston of the engine has been reduced by about 13 lb. per sq. in., and consequently the effective pressure of the steam on the piston of the engine is 13 lb. per sq. in. in excess of the steam pressure indicated by the steam gauge on the boiler or main steam pipe.

Condensers are of three types: surface condensers, jet condensers, and ejector condensers.

Surface Condenser. Fig. 41 is a sectional representation of a surface condenser, and it is seen that the principle of counter-currents is embodied in its construction. The shell is made of cast-iron, and the condenser tubes are attached to partitions of the same metal in the manner shown in the diagram. The body of the condenser must be designed to withstand a crushing load of 15 lb. per sq. in., and it is usual

to test it by an internal water pressure of 30 lb per sq in The condenser tubes are made of brass of No 18 I W G and ¾ in external diameter and when the water contains salt or corrosive matter the surfaces exposed to the action of the water are tinned. The lengths of the tubes vary from 4 to 15 ft, according to the size of the plant, and the number of tubes placed diagonally in 1 sq ft of the tube plate or

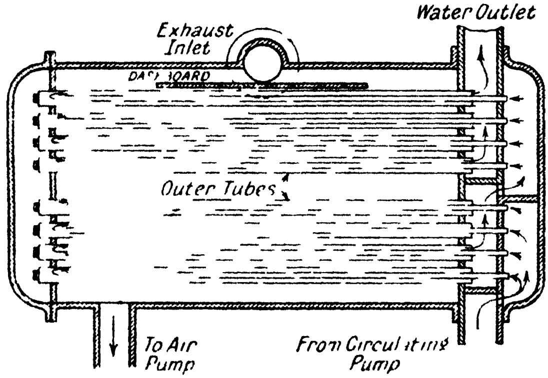


FIG 41 SURFACE CONDENSER

partition may be calculated by $N = 166 \div P^2$ where N is the number and P the pitch Standard designs for 26 in vacuum are usually based on a condensation of 10 lb of steam per square foot of surface when the inlet temperature of the circulating water is 60° to 65° F and the quantity of water 30 to 40 lb per pound of steam

It is seen that the cooling water enters at the bottom of the casing and passes through the tubes in the lower half of the condenser, after which it traverses the tubes in the upper half in the opposite direction and passes out at the outlet on the top of the casing The steam enters the casing centrally at the top and strikes the baffle plate at the top after which it passes down through among the tubes into the pipe leading to the air pump

Conditions Governing Maintenance of Vacuum. The vacuum[1] is subject to the following conditions:

Physical. 1. Steam load. 2. Amount of cooling water passing through the condenser. 3. Inlet temperature of the cooling water.

Mechanical. 1. The condition of the cooling surfaces on both sides of the tubes. 2. The capacity and performance of the air extraction plant.

In any existing plant, designed and installed for a specific set of conditions, the vacuum will fluctuate with change in any of the foregoing factors, but the chief dimensions of a new plant to fulfil a given set of conditions may be fixed after the required cooling surface has been ascertained by the use of the formula $S = \frac{1000D}{R\delta}$, where S is the cooling surface in square feet, D the lb. wt. of steam to be condensed per hour, R the number of heat units transferred per square foot of cooling surface per degree difference of temperature between the sides of the tubes per hour, and δ the mean temperature difference, that is, the difference between the steam temperature and the mean circulating water temperature.

Example 19. A condenser is to be constructed to deal with 50 000 lb. of steam per hour. If the rate at which heat is transmitted by the tubes is 500 B.T.U. per hour per square foot of surface, and the value of δ is 18, find the area of cooling surface of the condenser.

Solution.

$$S = \frac{1000 \times 50\,000}{500 \times 18} = 5555 \text{ sq. ft.}$$

Given the length and diameter of condenser tubes, the number may now be calculated as follows:

$$N = \frac{S}{\pi d l}$$

Jet Condenser. Whereas in the case of the surface condenser the cooling water and the exhaust steam are not

[1] "Steam Condenser Performance," by D. G. McNair, *Colliery Engineering*, May 1927.

allowed to mingle, and consequently the condensate may be used for feeding the boilers, it is a feature of the jet condenser that the cooling water comes into direct contact with the exhaust steam, and consequently the cooling water must be clean if the condensate is to be used for feeding the boilers. The jet condenser consists of a pear-shaped cast-iron vessel, which has a cooling water inlet reaching into the centre of the interior and a steam inlet pipe placed at the side on the same level as the termination of the water inlet pipe. The latter terminates in a slotted foot box with the openings all around the sides, so that the cooling water passes out horizontally, thus forming a wet screen in which the exhaust steam is effectively condensed. The condenser is most efficient, and produces a vacuum of about 27 in. of mercury when it is supported at a height of 30 ft. above the water in the hot well. An air-pump is fitted to the condenser to maintain the vacuum. The ejector condenser is similar to the jet condenser, but differs from it in that although it is necessarily placed at the same height above the water in the hot well, no air pump is fitted to it, for the vacuum is produced by the hydraulic head in the outlet pipe. Fig. 42 is a sketch of the jet condenser.

Compound Engines. The winding engines at Penallta Colliery, in South Wales, are of the double tandem compound type, with high-pressure cylinders 32 in. diameter and low-pressure cylinders 53 in. diameter, the stroke being 72 in., and at Clydach-Cambrian Colliery the engines are 28 in. × 48 in. × 66 in., having drop steam valves and Corliss exhaust valves. Many pumping engines, haulage engines, fan engines, and compressor engines are of similar construction The high-pressure steam is used expansively in the H.P. cylinder and then it is used expansively in the L.P. cylinder, being finally exhausted to the condenser at a pressure approximating to atmospheric pressure. It is possible in this way to more fully utilize the expansive property of steam than it is to do so in one cylinder, and consequently the steam is used more efficiently. At the beginning of this chapter figures are given to show the coal consumption per i.h.p.-hour, and these may

be taken as representing relatively the steam consumption for the different kinds of engines. In the design of compound engines the cylinders are proportioned so that the work done in the H.P. cylinder equals that done in the L.P. cylinder, the relative diameters of the cylinders being conditioned by the

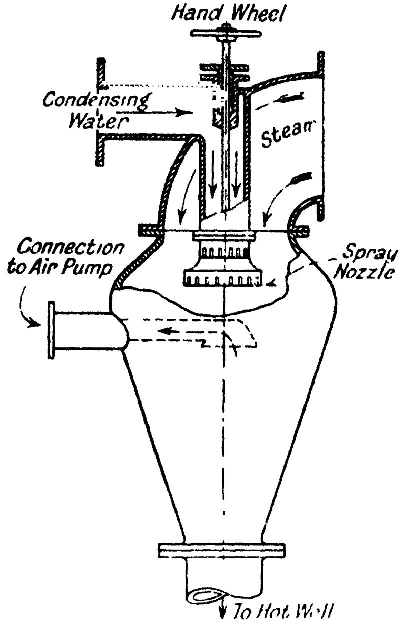


FIG. 42. JET CONDENSER

cut-off and ratio of expansion of the steam in the H.P. cylinder.

Steam Turbines. The steam turbine is the simplest of all heat engines, and may be described as a machine in which a gradual change of the momentum of a fluid is applied to produce rotation of the rotor and its shaft, thus enabling the calorific energy of the steam to be converted to mechanical energy. There are three kinds of steam turbine: 1 The De Laval or impulse turbine. 2. The Parsons or reaction turbine.

3. The impulse-reaction turbine, as represented by the Curtiss and other turbines.

De Laval Steam Turbine. In this type of turbine the calorific energy in the steam is converted into kinetic energy by expanding the steam in a divergent nozzle, or a series of nozzles, and allowing it to impinge on a series of blades mounted on the periphery of disc which is supported upon a shaft that is connected to speed-reducing gear. Fig. 43 shows the relative positions of the nozzles and the buckets attached to the periphery of the rotor disc, and as the throat of the nozzle is seen to diverge it is obvious that the steam will expand and that the pressure will fall. The lower portion of the figure shows that as the steam pressure falls from P_1 to P_f, the velocity of the steam increases from one end of the nozzle to the other, and diminishes as it passes across the face of the buckets to the condenser on the other side of the turbine. The velocity of the steam when it impinges on the buckets depends on the initial pressure of the steam and the dimensions of the nozzles, but if steam at 200 lb per sq. in. (gauge) be used, the velocity of the steam at the entrance to the nozzle may be about 2000 ft. per sec., and at the exit from the nozzle about 4000 ft. per sec It is capable of proof that the most efficient speed of the buckets is 50 per cent of the velocity of the steam at impingement This machine is extensively used for power

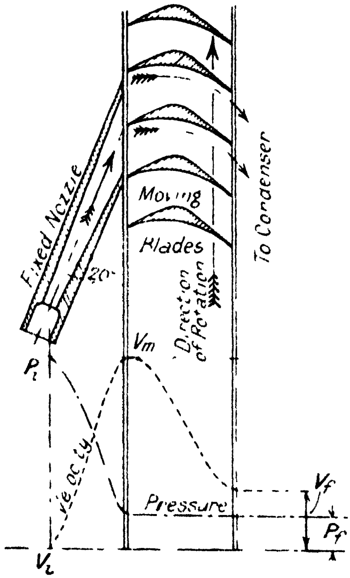


FIG. 43 DE LAVAL STEAM TURBINE

purposes in this country, and is made by Messrs. Greenwood & Batley, Ltd., of Leeds. The following particulars of De Laval turbines are of interest—

TABLE IV

SPEEDS OF DE LAVAL TURBINE WHEELS

Sizes of turbines h p.	Middle diameter of wheel in in	Revolutions per minute	Peripheral speed in ft per sec.
5	4	30,000	515
15	6	24,000	617
30	8¾	20,000	774
50	11¾	16,400	840
100	19¾	13,000	1115
300	30	10,600	1378

Parsons Steam Turbine. Fig 44 illustrates the setting of the blades of a reaction turbine, and it is seen that there are alternate rows of moving and fixed blades, the former being attached to the turbine shaft and the latter to the casing. In a turbine of this type, the gradual change of momentum of the steam takes place, due to drop in pressure, as the steam flows from the inlet towards the outlet or exhaust. The flow of steam is *axial*, that is, in the direction of the turbine shaft, but it may be *radial*, so that reaction turbines may be either axial-flow or radial-flow turbines. The expansion of steam is generally arranged to take place in three stages, and consequently the shaft increases in diameter from the inlet end towards the outlet in three definite steps

The admission of steam is controlled by a throttle valve and governed by means of a centrifugal governor in accordance with the variations of load and speed.

Impulse-Reaction Turbines. Fig. 45 shows the essential features of a turbine of this class, and it will be seen that the action of the steam on the first set of moving blades is that of direct impingement from diverging nozzles, whereas the action on the next set of moving blades is by the reaction

principle of the Parsons turbine. In the particular case of the Curtiss turbine each set of moving blades has a corresponding set of nozzles attached to diaphragms between the moving blades. In Fig. 45 it is seen that there are four sets of moving

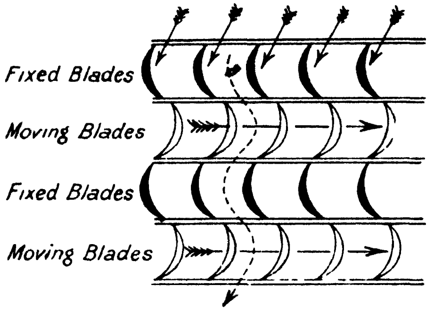


FIG 44 PARSONS REACTION TURBINE

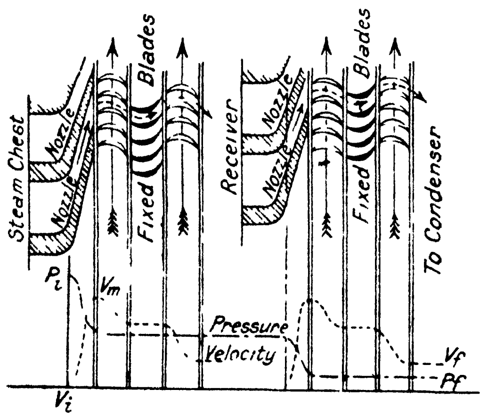


FIG 45 IMPULSE-REACTION TURBINE

blades, two sets of fixed blades, and two sets of divergent nozzles. The variations of steam pressure and velocity are also shown in the figure. These turbines are made in large sizes suitable for colliery work.

REFERENCE BOOKS

The Steam Engine and Gas and Oil Engines, by Perry.
Steam and Other Engines, by Duncan.
A Textbook of Heat Engines, by Jameson and Andrews
Motive Power Engineering (for Engineering and Mining Students), by Harris (Pitman).
Steam Turbine Theory and Practice, by Kearton (Pitman)
Mechanical Equipment of Collieries, by Percy.

EXERCISE QUESTIONS

1. Describe a governor for controlling the speed of a steam-engine and say how it does its work.
(*2nd Class Exam*., May, 1920.)

2. Make a sketch, with approximate dimensions, of an ordinary pedestal suitable for a haulage engine drum shaft 6 in. in diameter. State of what metal the various parts are made.
(*2nd Class Exam*., Oct., 1921.)

3. What is meant by an eccentric as used in engines? For what purpose are eccentrics used? Illustrate your answer with one or more sketches (*2nd Class Exam*., May, 1917.)

4. What is the difference between a condensing and a non-condensing engine? Why is condensing resorted to? Describe one form of condenser. (*2nd Class Exam*., May, 1917.)

5. Describe the link motion for reversing engines. Illustrate your answer by one or more sketches.
(*2nd Class Exam*., Nov., 1918.)

6. A steam-engine has two double-acting cylinders each 12 in. diameter by 18 in. stroke, and runs at 121 revolutions per minute. The mean effective pressure of the steam in the cylinders is 30 lb. per sq. in. The mechanical efficiency is 92 per cent. What is the indicated and brake horse-powers of the engine?
(*2nd Class Exam*., Nov., 1922.)

7. The engineer at a colliery reported to his manager as follows—"The split pin came out of the cotter securing one of the piston rods of the hauling engine to its crosshead. The cotter worked loose and came out." Make one or two sketches to explain the mishap, and say what damage might result to the engine. (*2nd Class Exam*., May, 1923.)

8. Make a full-size sketch of a pin to connect the slot-link of a Stephenson link gear to one of the eccentric rods of an engine. Show how the pin would be arranged to keep in position. State the material used in the pin and the treatment it should undergo to enable it to perform its work without excessive wear.
(*2nd Class Exam*., Nov., 1922.)

9. What is the difference between a compound steam-engine

and a simple steam-engine? Why is compounding resorted to?
(*2nd Class Exam*, Nov, 1919.)

10 For what purposes is a steam capstan engine employed at the top of a shaft? Compare the advantages and disadvantages of worm-gearing and spur-gearing for capstan engines
(*2nd Class Exam*, Nov, 1919)

11 Describe what is meant by the terms (*a*) cam, (*b*) eccentric (*c*) crank State a use for which each of these devices is best suited (*2nd Class Exam* May, 1931)

12 Describe with the aid of a sketch, one method of directing steam into the cylinder of an engine so as to drive the piston to and fro Name a method of ascertaining whether the steam is being used correctly and economically in the engine
(*2nd Class Exam* May 1931)

13 In connection with the cylinder of a steam engine what are the devices adopted and materials used

(*a*) to prevent steam passing between the piston and the cylinder wall,

(*b*) to prevent steam from escaping around the piston rod where it passes through the cylinder cover

(*c*) to make steam tight joints between the cylinder and the end covers? (*2nd Class Exam* May 1932)

14 Make sketches to show a connecting rod with small-end fitted with adjustable brasses and a strap and gib and cotter and a big end fitted with a marine type bearing Assume the cross head pin to be 2 in and the crankpin 3 in in diameter If the stroke is 2 ft, how long would you make the connecting rod from centre to centre of pins (*2nd Class Exam*, Nov 1932)

15 Describe a mechanism for reversing the direction of turning of a steam engine (*2nd Class Exam* Nov 1933)

16 Draw a typical indicator diagram taken from the cylinder of a steam engine in which cut off occurs at half stroke and the cylinder exhausts to atmosphere Assume an initial steam pressure of 80 lb per sq in (*2nd Class Exam* May, 1934)

17 Make sketches of a plummer block or pedestal and bearing for a shaft 4 in diameter with means for preventing endwise movement of the shaft The plummer block is to be bolted to a horizontal support (*2nd Class Exam*, Nov 1935)

18 What horse power would you expect from a steam engine having one cylinder 15 in bore 24 in stroke running at 80 r p m? The steam pressure at the stop valve is 80 lb per sq in The engine exhausts to the atmosphere
(*2nd Class Exam* May 1936)

19. What brake horse power would you expect from a double-acting steam engine with two cylinders 14 in. bore by 24 in. stroke running at 120 r.p.m., with a steam pressure of 80 lb. per sq. in. at the stop valve? Why is compounding adopted in steam-engines?

(2nd Class Exam., May, 193[illegible].)

20. Describe what happens inside the steam cylinder of an engine in one revolution of the engine which exhausts to a condenser. How is the steam supply controlled?

(2nd Class Exam., Nov., 1937.)

CHAPTER V

MECHANICAL TRANSMISSION OF POWER

SUCH is the variety of conditions under which power is transmitted and utilized in and about collieries that nearly every conceivable system has been used for transmitting power to winding and haulage gears, to electrical generators and air compressors, to coal-cutters and conveyors, to pumping and ventilating machinery, and to other incidental operations on the surface and underground.

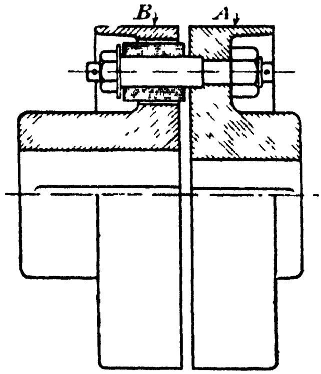


FIG. 46 (a)

We shall deal briefly with a few of the most common mechanical methods of transmitting power in this chapter and leave the consideration of electrical, pneumatic, and hydraulic transmission for later chapters.

Mechanical methods of transmitting power from one machine to another are as follows: (1) by shafting; (2) by belts; (3) by ropes; (4) by chains, (5) by gearing.

Shafts, and Methods of Joining Them. Shafts may be used as shafts of engines, when they may be either solid or hollow, or they may be used for transmitting power over considerable distances on the surface, when they are usually made of solid steel. A familiar case is that of the crankshaft of an engine or the drum shaft of a winding engine. When a drum shaft exceeds 10 in in diameter a hole must be bored axially from end to end to enable flaws to be located, but it may be advantageous to use hollow shafting when large powers have to be transmitted, for the sake of keeping the weight of the shafting

down to a minimum. Shafting is usually supported on plummer blocks, on solid foundations, or on wall brackets, and long lengths are joined together by flanged couplings or by muff couplings. When the connection is made to an electric motor the coupling is made flexible. Figs. 46 (*a*) and (*b*) show

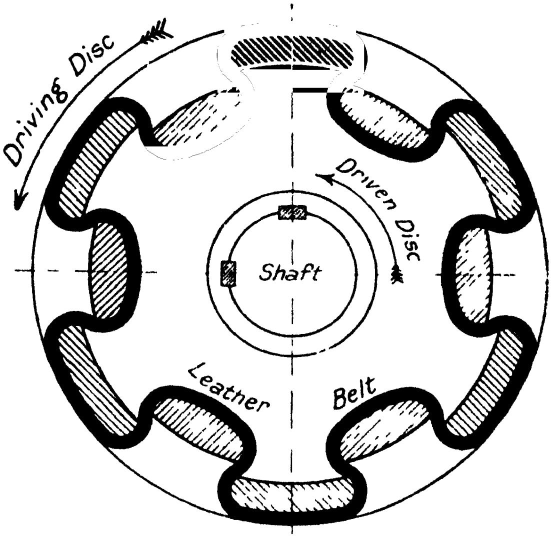


FIG. 46 (*b*). FLEXIBLE COUPLING.

two forms of flexible coupling. The figure on p. 92 shows that form of coupling in which the connection is made by pins in one flange passing through rubber-lined holes in the opposite flange. The above figure shows another form of coupling in which a belt is laced round an equal number of projections on the flanges. Such couplings are used mainly in order that the motor used to drive the shaft may have had time to develop the requisite torque before the load is taken up. No such coupling is necessary when an electric motor develops full torque at starting, or when the load may be applied gradually to the motor, as in the case, say, of a direct system of haulage.

Strength of Shafts. The stress applied to a shaft is always

a torsional one, tending to twist or turn the shaft. Let F be a force in pounds acting at a distance D from the centre of the shaft, and tending to cause the shaft to rotate, then the twisting moment is FD lb.-ft. Let f be the safe stress in pounds per square inch in the material; A the area of cross-section in square inches; d the diameter of the shaft in inches, and E_t the torsion modulus (0·5) of the material, then the resisting moment $= \frac{fAdE_t}{2} = \frac{\pi f d^2 \times d \times E_t}{4 \times 2}$. For stability, the turning moment must be equal to the resisting moment, thus

$$12FD = \frac{\pi f d^3 E_t}{8}, \text{ and}$$

$$d = \sqrt[3]{\frac{96FD}{3{\cdot}14 f E_t}} = \sqrt[3]{\frac{61{\cdot}1FD}{f}}$$

Example 20. The radius of a belt-driven pulley is 15 in., and the difference between tensions in the belt on the tight side and on the slack side is 1500 lb. Calculate the twisting moment in lb.-in., and the diameter of a steel shaft in which the safe stress is 8000 lb. per square inch.

Solution. Twisting moment $= 1500 \times 1{\cdot}25 = 1875$ lb.-ft.

$$d = \sqrt[3]{\frac{61{\cdot}1 \times 1875}{8000}} = 2{\cdot}43 \text{ in.}$$

If the shaft is short, no allowance need be made for bending, but if the shaft is heavy and the length exceeds fifteen diameters, it would be necessary to allow for bending moment by adding 25 per cent to the diameter of the shaft. In practice it might be considered necessary to provide a bearing at the middle of the shaft to reduce the bending moment, and thus avoid the need of the larger shaft.

Strength of Hollow Shafts. The resisting moment of a hollow shaft is less than the resisting moment of a solid shaft of the same external diameter because of the removal of the metal from the central portion of shaft. Let d_1 represent the

internal diameter of a hollow shaft having an external diameter *d*, then—

the resisting moment of a hollow shaft $= \frac{\pi f E_t}{8}(d^3 - d_1^3)$

It is easy to see that if a hole 2 in. diameter is bored longitudinally through a shaft 6 in. in diameter, that the resisting moment is $\frac{6^3 - 2^3}{6^3} = \frac{26}{27}$ths of the resisting moment of the solid shaft of the same external diameter. "Winding apparatus worked by mechanical power, if installed after 10th July, 1913, shall have the drum shafts, if 10 in. or more in diameter bored longitudinally at the centre" [General Regulation 80 (*b*)]. Whereas the strength of the hollow shaft here referred to is $\frac{26}{27}$ths of the solid shaft, the weight is $\frac{8}{9}$ths of that of the solid shaft, therefore the bending moment is also diminished.

Horse-power Transmitted by Shafts.

Twisting moment in lb.-ft. $= F$ (lb.) $\times$ D (ft.)

Work done per revolution $= 2\pi FD$ ft.-lb.

Work done per minute $= 2\pi FDN$ ft.-lb., where N is the number of revolutions per minute.

$$\text{H.p. transmitted} = \frac{2\pi FDN}{33{,}000}$$

Example 21. Calculate the horse-power transmitted by a shaft which makes 450 r.p.m., if the twisting moment is 22,500 lb.-in.

Solution.

$$\text{H.p. transmitted} = \frac{2\pi N}{33{,}000} \times \frac{\text{twisting moment (lb.-in.)}}{12}$$

$$= \frac{2 \times 3{\cdot}14 \times 450}{33{,}000} \times \frac{22{,}500}{12}$$

$$= 160$$

It is seen that the size of shaft required to transmit a certain horse-power at a given number of revolutions per minute can be found in two steps, thus—

$$\text{Twisting moment (lb.-in.)} = 12 \times \frac{33{,}000 \text{ h.p.}}{2\pi N}$$

$$\text{Resisting moment (lb.-in.)} = \frac{\pi f d^3 E_t}{8}$$

$$\therefore \quad d^3 = \frac{8 \times 33{,}000 \text{ h.p.}}{2\pi^2 f E_t N}$$

Example 22. Calculate the diameter of a steel shaft to transmit 140 h.p., if the shaft makes 32 r.p.m. and the safe stress in the material is 8000 lb. per square inch. $E_t = 0{\cdot}5$.

Solution. Diameter of shaft $= \left(\dfrac{12 \times 8 \times 33{,}000 \times 140}{2 \times 3{\cdot}14^2 \times 8000 \times 0{\cdot}5 \times 32} \right)^{\frac{1}{3}}$

$= 5{\cdot}59$ in.

Torque. Fig. 47 represents a belt passing round a pulley of radius R, the tension in the belt on the driving side being T_1, and the tension on the slack side T_2. In order that the pulley may be rotated there must be a difference between the tensions T_1 and T_2, and the difference between the tensions is the force producing rotation, the moment of the force, or torque, being $(T_1 - T_2) R$. The force is communicated to the pulley by the friction of the belt on the pulley.

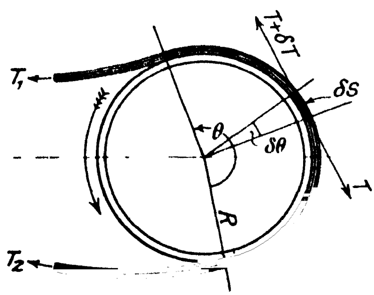


FIG. 47 TORQUE ON BELT PULLEY

Coil Friction. The simple theory of coil friction applies to belts of leather and ropes of cotton or steel, the essential difference being a difference in the value of the coefficients of friction, and not one of principle. Referring again to Fig. 47,

in which R is the radius of the pulley and θ the angle embraced by the belt on the pulley, it will be seen that the driving couple $= (T_1 - T_2)R$, and it will be understood that the resisting couple is that due to the machine being driven by the shaft of the pulley. The value of T_1 is limited by the strength of the belt, and the value of $T_1 - T_2$ is limited by the friction between the band and the pulley. Considering an element δS of the belt embracing the small angle $\delta\theta$ on the rim of the pulley, let T be the normal reaction of the belt on the pulley per unit of length in pounds. If we suppose the band to be just on the point of slipping, the conditions may be represented by—

$$(T + \delta T) - T = \mu T \delta S \text{ nearly}$$

$$\therefore \delta T = \mu T \delta S = \mu T \delta\theta$$

$$\text{hence } \frac{\delta T}{T} = \mu\delta\theta$$

Taking the sum of the elementary forces between T_1 and T_2, and expressing them in terms of the whole angle θ embraced by the band, we get as a limit—

$$\sum_{T_2}^{T_1} \frac{dT}{T} = \mu \sum_{0}^{\theta} d\theta \text{ which becomes } \log_e \frac{T_1}{T_2}$$

$$= \mu\theta, \text{ and } \frac{T_1}{T_2} = E^{\mu\theta}, E \text{ being } 2{\cdot}718, \text{ the base}$$

of the Napierian logarithmic system. If the coefficient of friction of belting on iron be taken as $0{\cdot}3$, and $\theta = \frac{2}{5} \times 2\pi$ radius, we shall find the ratio of T_1 to $T_2 = 2{\cdot}718^{0\cdot 3 \times \frac{2}{5} \times 2\pi}$ $= 2{\cdot}718^{0\cdot 74} = 2$, thus showing that in practice it may be assumed in the absence of precise data that $T_1 = 2T_2$.

Coefficients of Friction. The figures given on page 98 are intended to be useful as guides in calculations in which friction is a factor.

Strength of Leather Belts. The ultimate strength of leather belting varies from about 3500 lb. per sq. in. to 9000 lb. per sq. in. Light single belts are about $\frac{7}{32}$ in., and heavy single belts about $\frac{5}{16}$ in. in thickness. The working stresses in belts of

one ply varies from about 70 lb. to 100 lb. per in. of width, but the working stresses for light double belts ($\frac{7}{16}$ in. thick) and heavy double belts ($\frac{9}{16}$ in. thick) are 140 lb. and 180 lb. per in. of width, respectively. These figures should be used with reservation, since the actual working stress in a belt must depend on the manner in which the joint is made, the permissible stress being greater for laced belts than for belts that are joined by metal fasteners.

Metal on metal, with lubrication	0·03–0·08
Iron to iron or brass	0·15–0·20
Iron to copper	0·18–0·20
Iron to steel	0·20–0·30
Leather on metal, dry	0·30–0·40
Leather on metal, oily	0·25–0·35
Pine on steel or brass, dry	0·16–0·19
Elm on cast iron, dry	0·20–0·25
Oak on cast-iron, dry	0·35–0·45
Ferodo on metal	0·35–0·45

Speed of Belts. The speed at which belts are made to run depends on the speed of the driven machine, but experience shows that whereas the speed may approach 6000 feet per min., the best practice is to run main belts at a speed of about 3500 ft. per min.

Power Transmitted by Belting. Generally speaking, the power that can be transmitted by a belt is limited by the friction between the belt and the pulley. When excessively loaded a belt usually slips rather than breaks, hence the friction is an important factor in deciding upon what power can be transmitted by a given belt, or in determining the width of belt for a given duty. The maximum power that can be transmitted by a belt running at a given speed is given by the expression—

$$\text{H.p.} = \frac{(T_1 - T_2)2\pi RN}{33{,}000} = \frac{(T_1 - T_2)V}{33{,}000} = \frac{\left(T_1 - \dfrac{T_1}{E^{\mu\theta}}\right)V}{33{,}000}$$

$$= T_1\left(1 - \frac{1}{E^{\mu\theta}}\right)\frac{V}{33{,}000}$$

Example 23. A mine fan is driven by a belt which is 24 in. wide and ¼ in thick, the speed of the belt being 3000 ft per min.

Assuming that the tension per inch of width of the belt is 150 lb., that the coefficient of friction is 0·3, and that the angle embraced by the belt on the motor pulley is two-fifths of 2π radians, calculate the power given out by the motor.

Solution. $$\text{H.p.} = 24 \times 150\left(1 - \frac{1}{2{\cdot}718^{\frac{4\pi}{5}}}\right)\frac{3000}{33{,}000} = 173{\cdot}5$$

Care of Belts. Belts should be kept clean and free from accumulations of dust and grease, and particularly lubricating oils some of which permanently injure the leather. They

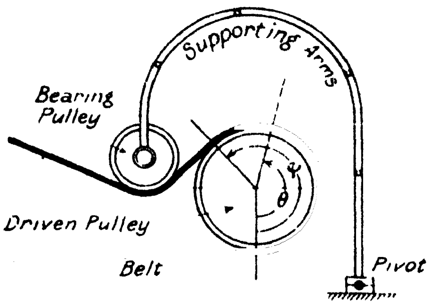


FIG. 48. LENIX BELT DRIVE

should be kept free from water and moisture, and should be treated with a dressing consisting of two parts of tallow and one of fish oil. Should a belt slip when it is maintained in good condition, it may be concluded that a wider belt is necessary, or that the angle embraced by the belt on the pulley is smaller than it should be.

Lenix Belt Drive. It is true to say that a belt drive is generally more efficient when long than when the distance between the driven pulley and driver centres is small. It may be that the distance must be comparatively small and that the reduction of speed is large, when the ratio of the diameter of the driven wheel to that of the driver will be great.

In that case the arc of contact may be increased by the adoption of the Lenix belt drive illustrated in Fig. 48. In the normal case the arc would be θ, but by placing the weighted

drum on the belt in the position shown the angle is increased to φ, consequently the gripping power of the belt is increased.

Belt Pulleys. The proportion of the diameters of two pulleys working together should not as a rule exceed 6 to 1, but the Lenix device may be used when the ratio is greater or the centres are too close. It is an advantage to have a camber on the surface of the pulleys from $\frac{1}{8}$ to $\frac{1}{4}$ in. per ft. of width,

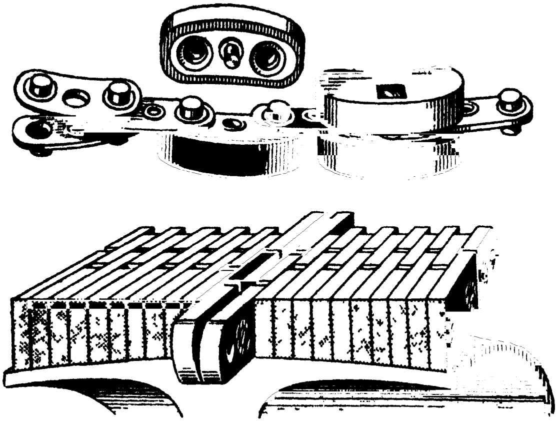
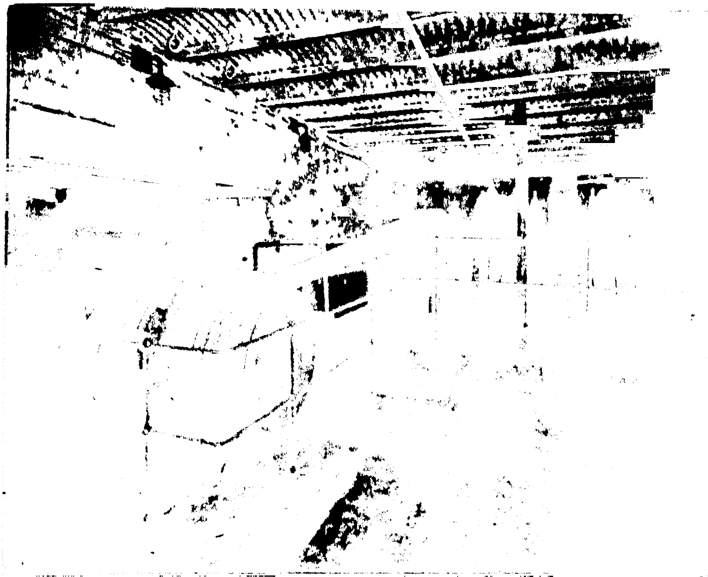


FIG. 40. LINK LEATHER BELTS.

both pulleys in a gear having the same convexity. The face of the pulley should be 1 to $1\frac{1}{2}$ in. wider than the belt. Pulleys may be made of cast-iron throughout, or they may be made of wrought-iron arms and steel rim built up on a cast-iron boss.

Link Belts. Link belts may be designed to run in V-grooved pulleys or they may be shaped to run on the common form of cambered pulley used for belt drives. The Lotus link belt made by Garnett, Whiteley & Co., Ltd., Liverpool, is of the former type, and is suitable for light drives. The belt consists of a steel chain, comprising outer and inner pressed steel cup bearing plates. The side plates that engage with the sides of the grooves on the pulleys are made of strong rubber, and they are fastened to the steel chain by means of a stud and nut through the outer links. Advantages of this form of link belt

are that there is no possibility of links working loose, *stretch* is eliminated, and the presence of the rubber side-plates prevents slip. The upper portion of Fig. 49 shows the construction of the Lotus belt, and the lower portion of the figure shows the



(*Wm. Kenyon & Sons, Dukinfield*)

FIG. 50. ELECTRIC MOTOR DRIVING ENDLESS ROPE

construction of the link belt designed for heavy drives by John Tullis & Son, Ltd., Glasgow. In addition to being shaped on the undersurface to the camber of the pulleys, the belt has a flexible centre which ensures that it takes a firm grip of the pulley without straining the rivets and without loss of power from slip. Belts of this construction are sometimes used in heavy haulage gears to effect the first reduction of speed from the pulley on the motor shaft to the pulley on the second-motion shaft.

Cotton Ropes. These ropes are now extensively used in

driving colliery fans, underground haulages, and in transmitting power from a steam engine to an electrical machine. They are made of cotton, having a varying number of strands in the rope, but the rope recommended by William Kenyon & Sons, Ltd., Dukinfield, consists of three strands. The coefficient of friction of cotton ropes may be taken at 0.2, so that when the power to be transmitted is known it will be possible to determine the number of belts. The ultimate strength of cotton ropes is determined by tests to vary according to the diameter of the ropes, and it may be expressed as $T = 6500d^2$, where T is the breaking stress in pounds and d is the diameter in inches. The working stress may be limited to $\frac{1}{..}$th of the breaking stress. Owing to the centrifugal force operating on ropes running at high speeds and tending to cause the driving pulley to slip within the ropes, it is desirable that the rope speed should not, as a rule, exceed 4000 to 5000 ft. per min. Fig. 50 shows an electric motor driving an endless-rope haulage gear through eight cotton ropes and steel spur gearing, the haulage ropes themselves being coiled on *fleeting* pulleys. Assuming that the angle embraced by the ropes on the driving pulley is $\frac{4\pi}{5}$ radians, and that the value of μ is 0.28, we shall find that $2.718^{\mu\theta} = 1.65$, and that $T_1 = 2T_2$. Having found the difference between the tensions and the relation of one to the other, we may then determine the number of ropes of a certain diameter to transmit a given amount of power, for the h.p. $= (T_1 - T_2)V \div 33000$, as for belts.

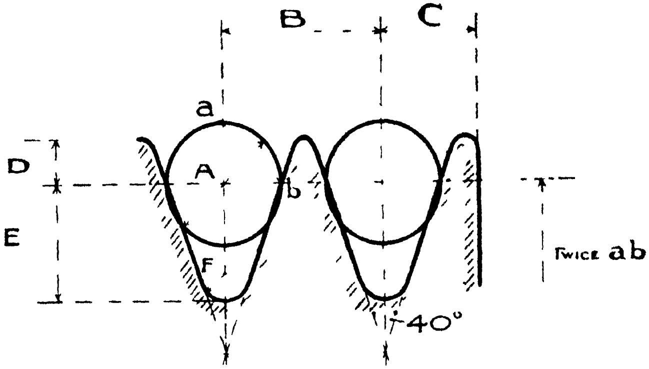
Example 24. A 70 h.p. motor is to be used to drive a haulage gear through cotton ropes 1 in. diameter, running at a speed of 4000 ft. per min. Calculate the number of ropes required, assuming $f = \frac{1}{20}$.

Solution. $T_1 - T_2 = \frac{33000 \text{ h.p.}}{V} = \frac{33000 \times 70}{4000} = 578$ lb.

$$T_2 = \frac{T_1}{2} = 0.5T_1$$

$T_1 - T_2 = T_1 - 0.5T_1 = 0.5T_1 = 578$, and $T_1 = 578 \div 0.5 = 1156$ lb.

and, since the ropes are to be 1 in diameter and, therefore, have an ultimate breaking stress of 6500 lb the number of ropes required for the transmission of the necessary power $= \dfrac{1150 \times 20}{6500}$ $= 3.5$ It would be necessary to provide 4 ropes



DIA ROPE A	IN $\frac{1}{2}$	IN $\frac{5}{8}$	IN $\frac{3}{4}$	IN $\frac{13}{16}$	IN $\frac{7}{8}$	IN 1	IN $1\frac{1}{8}$	IN $1\frac{1}{4}$	IN $1\frac{3}{8}$	IN $1\frac{1}{2}$	IN $1\frac{5}{8}$	IN $1\frac{3}{4}$	IN $1\frac{7}{8}$	IN 2
PITCH B	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{5}{16}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{11}{16}$	$1\frac{7}{8}$	$2\frac{1}{16}$	$2\frac{3}{16}$	$2\frac{3}{8}$	$2\frac{9}{16}$	$2\frac{3}{4}$
C	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{25}{32}$	$\frac{13}{16}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$
D	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{19}{32}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{23}{32}$
E	$\frac{1}{2}$	$\frac{19}{32}$	$\frac{23}{32}$	$\frac{25}{32}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{1}{16}$	$1\frac{3}{16}$	1 [illegible]/16	1 [illegible]/32	1 [illegible]/16	$1\frac{21}{32}$	$1\frac{3}{4}$	$1\frac{27}{32}$
F	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{15}{32}$

(Kenyon & Sons Ltd

FIG. 51 SECTION OF RIM OF A ROPE PULLEY

Cotton Rope Pulleys Pulleys under 8 ft in diameter are usually cast in one piece between 8 and 12 ft in diameter in halves and pulleys of larger diameter are built up in segments The width of the pulley face depends on the number of ropes, and is usually made to have the width $N \times$ pitch of grooves $+ 1\frac{1}{2}$ in Fig 51 shows the form and proportions of the 40°-groove pulley made by Kenyon & Sons, Ltd It is obvious that the greater the distance between pulley centres the more

efficient will be the transmission. Since the arc of the driving pulley embraced by the ropes is dependent on the distance between pulley centres and the diameter of the driven pulley and the driver, the diameter of the driver should not be less than twenty times the diameter of the ropes, and should preferably be thirty times.

Transmission of Power by Wire Ropes. Wire ropes are sometimes used to transmit power from an engine on the surface of a mine to a haulage gear at the bottom of the shaft, or the main endless rope of a haulage system may be used to transmit power to a haulage gear placed at the inbye end of the haulage plane. Power may be transmitted in the same way to pumps placed at inbye points in a mine in which it would be unsafe to have electrical plant, and where compressed air was not available. A close examination of Fig. 50 will show that the pulley round which the wire rope passes gradually diminishes in diameter from one side to the other. This form is necessary to enable the rope to slip from the on-going side to the side at which the rope leaves the pulley, and the width of the throat must be sufficient to take the requisite number of turns of rope to ensure that the latter does not slip round the pulley. The number of turns of rope is determined by the formula $\frac{T_1}{T_2} = E^{\mu\theta}$. The central portion of the fleeting or Clifton pulley is cast in one piece, and the tapered throat is formed by wrought-iron segments which are bolted to the centre, and are therefore renewable. The coefficient of friction between a steel rope and the iron wheel is usually taken as 0·15 in making calculations regarding the number of turns of rope required to enable the requisite amount of power to be transmitted. When the load on the wire rope is a varying one it is usual to provide a tension arrangement consisting of a loaded carriage to ensure that the tension T_2 will always be adequate.

Example 25. The tractive force necessary to operate an endless rope haulage is 3000 lb. If the tension on the slack side of the

rope is 1500 lb., calculate the number of turns of rope required on the pulley to prevent the rope from slipping $\mu = 0{\cdot}15$

Solution. Since $\frac{T_1}{T_2} = E^{\mu\theta}$, and $\frac{3000}{1500} = 2{\cdot}718^{0{\cdot}15\theta}$, we get that

$$\log\left(\frac{3000}{1500}\right) = 0{\cdot}15\theta \log. 2{\cdot}718, \text{ therefore } \theta = \frac{\log 2}{0{\cdot}15 \log 2{\cdot}718}$$

$$= \frac{0{\cdot}3010}{0{\cdot}15 \times 0{\cdot}4343} = \frac{0{\cdot}3010}{0{\cdot}06515} = 4{\cdot}6 \text{ radians}$$

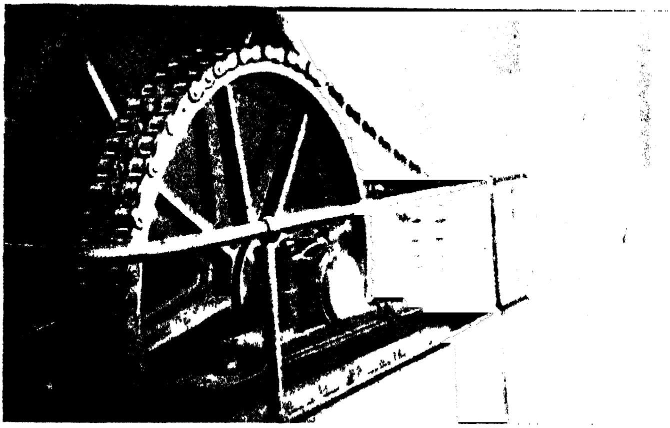


FIG. 52. RENOLD BUSH ROLLER CHAIN

There are 2π radians in one turn, and as the turns usually increase by 1 from ½, the number of turns in such a case as this would, in practice, be 1½. Obviously, the calculation enables the smallest number of turns to be calculated for given conditions.

Chain Drives. High efficiency, compactness, and silence in running are the chief advantages of chain drives. Several forms of link-chains are available for general driving purposes, but we need not do more than direct attention to two forms of chain that are commonly used in transmitting power in mines. The drive shown in Fig. 52 consists of two strands of 2·75 in. pitch Renold bush roller chain, and it is seen that the pins by which the double links are connected are surrounded by

steel rollers. Since the components of the chain are in tension they are made of high tensile steel, and the bearing surfaces are all case-hardened to ensure that the joints will wear well. When the distance between the centres of the driving and driven pulleys is necessarily short, it becomes necessary to use a chain having the highest degree of flexibility, and that

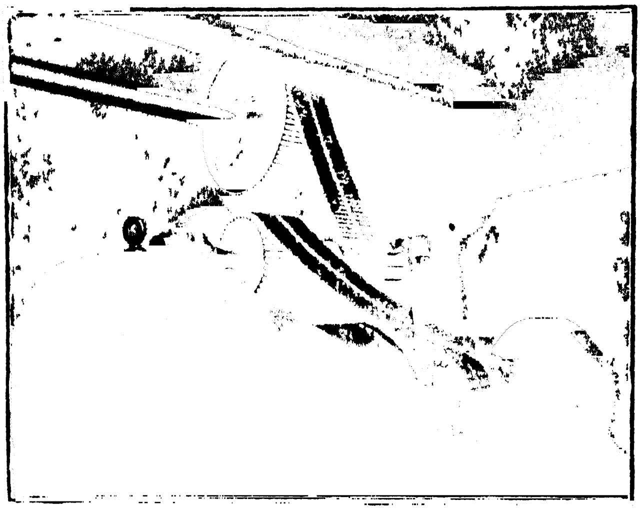


FIG. 53.

is possessed by the Renold inverted tooth chain shown in Fig. 53. Both forms of chain are used widely in mining work for the transmission of power and in operating mechanisms which are normally connected by gearing. Chain wheels of the smaller sizes are usually made of high carbon steel, and those of larger size are made of special close-grain cast iron or cast steel. The teeth are machine cut and case-hardened to enable them to withstand bending and shearing stresses and to wear well. The number of strands used in a gear depends on the power to be transmitted and consequently the width of the chain wheels is similarly dependent on the power to be transmitted.

Transmission of Power by Gearing. Although the normal relation between a driven pulley and the driver is such that the shafts are parallel, but may be in different horizontal planes, belts, single cotton ropes, and wire ropes, may be used to connect two pulleys the shafts of which are not parallel. Belts or ropes may be crossed to enable the direction of rotation of the driven pulley to be reversed, and guide pulleys may have to be erected to ensure that the belts or ropes will leave the driver and approach the driven pulley in proper alignment. Similar results may be obtained by transmitting power from one machine to another through toothed or worm gearing.

Toothed Gearing. The teeth in gear wheels may be *cycloidal* when the outline is formed by two curves that, commencing at the pitch line, curve in opposite directions, or they may be of the form of the *involute*. The teeth may be open, or if it is desired that the teeth of cast gears should have the maximum strength, they may be shrouded. When one of a pair of gear wheels is much smaller than the other, that alone is shrouded throughout the whole depth of the teeth. Meshing gear wheels of similar sizes may be shrouded up to the *pitch line*, that is the line upon which the wheels might be said to roll one upon the other. Gear wheels may be made of wood, raw hide, phosphor-bronze, cast-iron, or cast steel. For mining work, gear wheels are commonly made of cast-iron or cast-steel, but the pinions of high-speed machines may be made of raw hide, especially where silent running is desirable. Coal cutter gear wheels are usually made of manganese cast-steel, or they may be made of mild steel, the teeth being cut in the forged blank and afterwards case-hardened. Larger sizes of toothed wheels are cast. The length of the teeth may be parallel to the axis of the wheel, or, as in the case of *helical* gears, the teeth may be set diagonally across the face of the wheel in single formation or double herring-bone formation. The advantage of helical gears is that at any instant there are a greater number of teeth in contact than there are with ordinary spur gear wheels, and this makes for greater strength and smoothness of running.

Horse-power Transmitted by Spur Gearing. The power that a gear is capable of transmitting depends on the strength of the teeth, of which the shape is an important factor, and the permissible speed. In workshop practice the Lewis formula is used to determine the safe load (W lb.) when f, the safe stress in lb. per sq. in.; p, the circular pitch in inches; F, the width of the tooth face in inches; and k, a constant depending on shape of tooth, are known. Having found the safe load and the pitch-line velocity, the horse-power may be calculated, thus—

$$W = kFpf \text{ lb. and h.p.} = \frac{kFpfV}{33{,}000}$$

The value of k for gears having different numbers of teeth are—

No. of teeth	12	16	20	25	30	40	60	100	150
k	·078	·094	·102	·108	·114	·124	·134	·142	·146

The livelier the load on any structure in mechanics the less is the safe stress in the material, and that, obviously, varies according to the material used in making the gear wheels. The following is a statement of the relation of pitch-line velocity to the working stresses in cast-iron and steel.

Pitch line velocity in ft. per min.	200	300	600	900	1200	1800	2400
Cast iron (f lb. per sq. in.)	6000	4800	4000	3000	2400	2000	1700
Cast steel (f lb. per sq. in.)	15000	12000	10000	7500	6000	5000	4250

Example 26. Find the horse-power that can safely be transmitted by a cast-iron toothed gear wheel having 20 teeth with a circular pitch of $1\frac{1}{4}$ in. and a face width of 4 in., if the pitch line velocity is 300 ft. per min.

Solution. $$\text{H.p.} = \frac{0{\cdot}102 \times 4 \times 1{\cdot}25 \times 4800 \times 300}{33{,}000}$$

$$= 22{\cdot}3$$

Had the gear wheel been made of cast-steel, it would have been capable of transmitting $2\frac{1}{2}$ times the power of the cast-iron pulley.

Velocity Ratio of Wheel Trains. Fig. 54 shows three arrangements of gear wheels. Since the meshing wheels have the same shape of teeth, the proportion of diameter of wheel to number of teeth will be the same for both wheels, thus $\frac{d_1}{N_1} = \frac{d_2}{N_2}$, but the proportion of number of teeth to number of revolutions per minute (R_1 and R_2) will be inverse, $\frac{N_1}{N_2} = \frac{R_2}{R_1}$, or $N_1R_1 = N_2R_2$, thus

Speed of wheel B = speed of wheel A $\times \frac{N_1}{N_2}$, and

Speed of wheel D = speed of wheel $A \times \frac{N_1}{N_2} \times \frac{N_3}{N_4}$

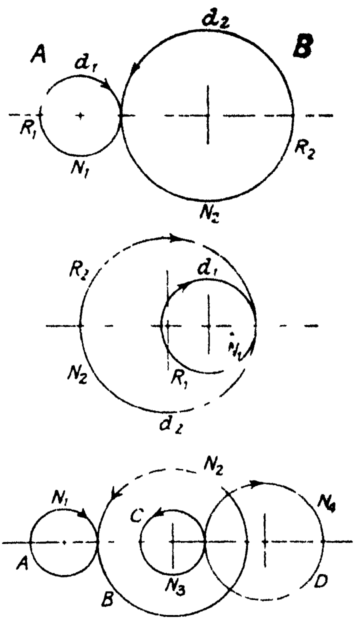


FIG. 54. WHEEL TRAINS

Example 27. The pinion on the armature shaft of an electric motor makes 450 r.p.m., and it has 15 teeth. The spur wheel meshing with the pinion has 70 teeth. What is the speed reduction and the revolutions of the spur wheel?

Solution. Speed reduction $= \frac{70}{15} = \frac{4\frac{2}{3}}{1}$

Revs. of spur wheel $= \frac{450 \times 15}{70} = \frac{450}{4\frac{2}{3}} = \frac{450 \times 3}{14}$

$= 96{\cdot}43$ per min.

Example 28. The pinion wheel on a motor shaft makes 500 r.p.m. and it has 15 teeth. The spur wheel with which it meshes on the second-motion shaft has 45 teeth. Another pinion wheel

on the second motion shaft has 20 teeth and it meshes with a spur wheel on a drum shaft, the latter having 60 teeth. Find the rate at which the drum shaft revolves and state the speed reduction.

Solution.

$$\text{Rotation of drum shaft} = \text{rotation of motor pinion} \times \frac{N_1}{N_2} \times \frac{N_3}{N_4}$$

$$= 500 \times \frac{15}{45} \times \frac{20}{60}$$

$$= 55.5 \text{ r.p.m.}$$

$$\text{Speed reduction} = \frac{45}{15} \times \frac{60}{20} = \frac{9}{1} \text{ or } 9 \text{ to } 1.$$

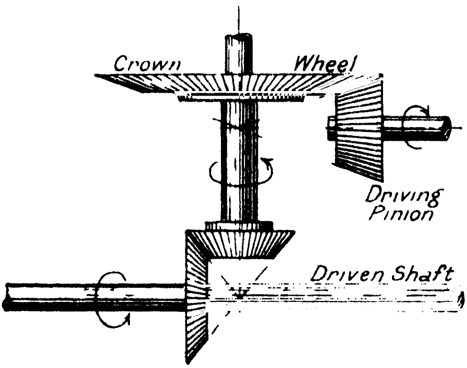


FIG. 55.—BEVELLED GEAR.

The student will readily appreciate the truth of the handy rule which states that the speed of a driven shaft equals the speed of the driving shaft multiplied by the product of the numbers of teeth in the driving wheels divided by the product of the numbers of teeth in the driven wheels.

Use of Bevel Pulleys. There are many examples to be found about a colliery for the need of bevel pulleys. Fig. 55 represents a case in which the motion of one shaft is communicated to another the axes of which may be in the same vertical plane but not in the same horizontal plane. It is easy to see that the only condition to be conformed to is that the axes of shafts

coupled in this way should intersect The lower shaft might well have been shown perpendicular to the plane of the paper Those who know the structural features of the Mavor & Coulson bar coal cutting machine will recognize in the figure a skeleton sketch of a portion of the gear contained in the gear head of that machine and everyone will see that the bar may be disconnected from the crown pinion by raising the mitre wheel vertically

Worm-gear. The extending application of electricity to the driving of different kinds of machines about coal mines

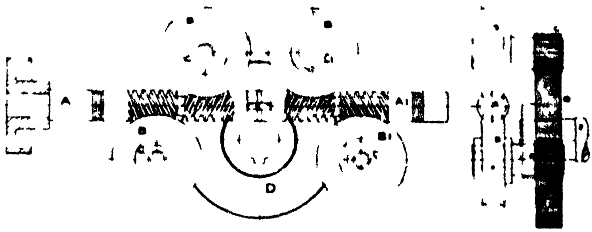


FIG. 56. SPENCE-WILD REDUCTION GEAR

and the improved design of worm gears have led to the more extended use of the latter When it is desired to change the direction of rotation from one shaft to another when their axes do not intersect and where the change must be effected within the limits of a very small space that may be done with considerable efficiency by means of worm gearing The efficiency of worm gearing depends on the diameter pitch and pitch line velocity of the worm and on the accuracy, smoothness and lubrication of the worm and the worm-wheel Worm gearing is used in the construction of compact conveying and haulage gears

Spence-Wild Reduction Gear The arrangement of this gear is shown in Fig 56, and it is seen that the gear comprises worm drives with a further reduction of speed by spur and pinions Of these two reductions the first is a perfectly balanced, thrustless, double worm gear, consisting of a worm-shaft A, having right and left hand worms gearing into their

respective worm-wheels B. These rotate in the same direction, being mounted on opposite sides of the worm-shaft. The second reduction is of the spur type, consisting of two pinions C, gearing into a common spur wheel D, keyed on to the final speed shaft. The worm-wheels are mounted on the pinions. By fitting another similar worm-shaft A, and accompanying worm-wheels B, and spur pinions C, the reduction can be approximately doubled without increasing the size of the box. A cross-coupling E is fitted between the worm-shafts to allow an endwise movement, enabling the load to be equally distributed. The worm-shafts are carried in long gun-metal bushes, covering the full length of the shafts, with pieces cut away to take the worm-wheels. The latter, together with the pinions, are provided with long gun-metal bushes running on fixed spindles. The final shaft F is mounted on roller bearings. The complete assembly is housed in an oil-tight, cast-iron box, presenting a neat and compact appearance. This is filled with oil to a correct level, and no further attention is necessary.

Clutches. When it is desired to engage a stationary portion of a machine with another part already in motion, or to release one part from the other when running, a device called a clutch is used. There are several kinds of clutch in use in connection with mining machinery. The simplest form of clutch is the block or jaw clutch, which consists of two similar castings of circular shape having three segmental projections which fit into three corresponding recesses, thus enabling the two portions of the clutch to be locked in position so that the power in a rotating shaft may be transmitted to the driven pulley or drum. One part of the clutch is fastened to the pulley or drum to be driven, and the other part is loosely fitted to the shaft, and is arranged to slide along a feather seated in the shaft. The movable part of the clutch is operated by lever and linkwork. Such a simple clutch is suitable for a main rope haulage gear, for the clutch is inserted when there is no load on the drum and when the engine or motor is rotating slowly, and it is withdrawn when it is unnecessary to run the engine while the train of tubs is running inbye under the control of the brake.

Friction Clutch. A friction clutch consists of two principal parts, the outer fixed part which is rigidly attached to the machine to be driven, and the inner movable part which is rigidly attached to the driving shaft, but is capable of being expanded within the outer part with such force as to drive the outer part round by friction. Such a clutch may be used to connect sections of shafting or to impart the motion of a

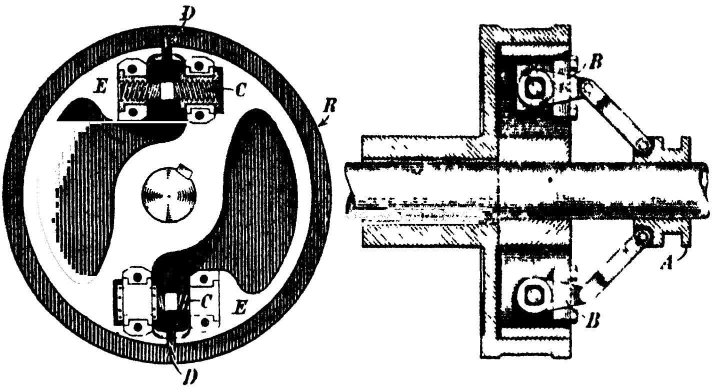


FIG. 57 FRICTION CLUTCH

rotating shaft to a stationary drum or pulley, and it is a feature of a friction clutch that the engagement may be effected quite slowly so that the load on the driving engine or motor is increased gradually from zero to full load. Fig. 57 shows a front view of the clutch and a sectional elevation of the clutch and the mechanism by which it is operated. It will be readily understood that as the sleeve A is pushed to the left the levers BB are turned outwards, thus turning the right and left-handed screws CC in the direction necessary for the extension of the distance D between the sockets, and so thrusting the parts EE against the clutch ring R, which is attached to the mechanism to be driven. Although the engaging parts of the clutch are usually made of iron, the central part may be lagged with hard wood logs or other clutch lining.

Centrifugal Clutch. Fig. 58 shows a Broadbent centrifugal clutch such as might be used for coupling an electric motor to

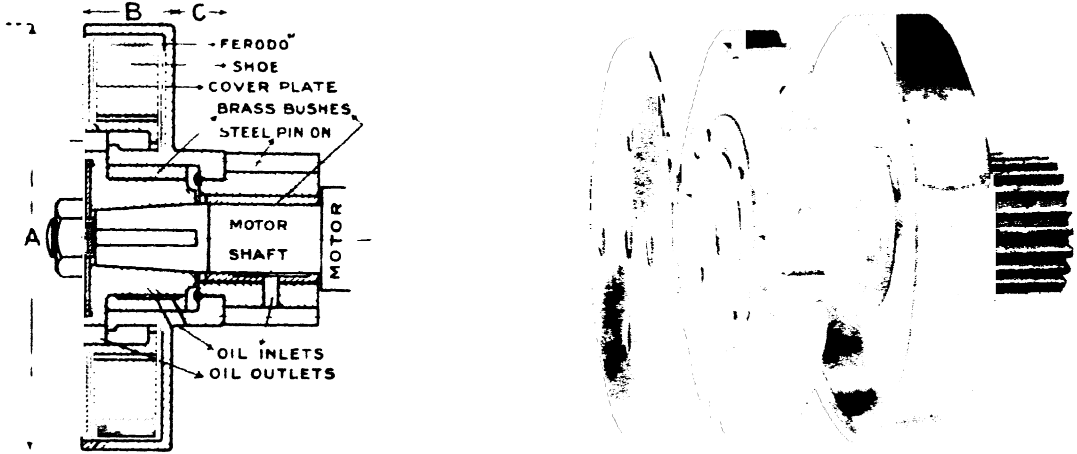


FIG. 58 BECADENE CENTRIFUGAL CLUTCH

a haulage gear. The clutch consists of two main parts, a loose exterior rim and a fast interior spider. The spider is keyed to the motor shaft and carries with it a number of loose shoes that are contained in suitable pockets. Each of the shoes is lined with "Ferodo" fabric on the outer face. As the motor speed increases from rest, the shoes are thrown out radially by the centrifugal force generated in them, and they engage with the interior cylindrical surface of the loose rim and cause the latter to rotate at the same speed as the motor. It is an advantage of this form of clutch that its action is automatic and gradual, and that when full speed has been attained the full load is applied to the motor; thus it serves the same purpose as the flexible coupling or friction clutch already described. In a modified form of the clutch the shoes have springs attached to them to prevent the engagement of the shoes with the rim until the motor (A.C. single phase or D.C. shunt wound) has been accelerated to 75 per cent of its full speed. The clutch may also be fitted with a hand controlled release by which the shoes may be disengaged without altering the speed of the motor. Steel rollers on a sliding sleeve, operated by a hand lever, engage with levers turning on pins in the central spider to press the levers towards the driving shaft, thus drawing back the shoes by the bolts which secure them to the levers.

REFERENCE BOOKS

Theory of Machines, by [illegible] and Kersey.
Mechanical World Year Book.
Machine Drawing and Design, by Low and Bevis.
Mechanical Equipment of Collieries, by C. M. Percy.
Applied Mechanics, by Jamieson and Andrews.
Fencing and other Safety Precautions for Machinery at Mines, H.M. Stationery Office.

EXERCISE QUESTIONS

1. A pair of gear wheels have teeth of 1 in. circular pitch. The pinion turns at 600 r.p.m. and has 1[illegible] teeth. The wheel meshing with it is to turn at 200 r.p.m. How many teeth will the spur wheel have, and what will be the distance between centres of the wheel and pinion when in correct mesh?

(2nd Class Exam., Nov., 1932.)

2. Mention and briefly describe three forms of clutch, and indicate how they are used in mining machinery and for what purposes. *(2nd Class Exam.*, Nov., 193[illegible].)

3. In connection with gear wheels, what is meant by the terms: (*a*) pitch line, (*b*) circular pitch, and (*c*) double helical teeth?
(*2nd Class Exam.*, Nov., 1934.)

4. What is a flexible coupling? In connection with what kinds of plant are flexible couplings used? Describe one form of flexible coupling. (*2nd Class Exam.*, Nov., 1937.)

5. Enumerate the types of drive available for transmitting power from an electric motor to a fan or a pump or a haulage gear. State the conditions suitable for each type of drive. What is a Vee-rope drive? (*2nd Class Exam.*, May, 1938.)

6. Make sketches showing a portion of the rim of a gear wheel:
(*a*) having machine-moulded straight spur teeth shrouded to the pitch line;
(*b*) having straight machine-cut spur teeth of involute profile;
(*c*) having machine-cut double helical teeth.
(*1st Class Exam.*, Nov., 1935.)

7. The boss of a gear wheel is 6 in. through from face to face and is bored 5 in. diameter, being a sliding fit on the shaft. Design and draw full size a key to suit the gear wheel and shaft, showing all useful dimensions and stating the material to be used for the key. Is it a good practice to make a key to fit top and bottom as well as on the sides? (*1st Class Exam.*, May, 1936.)

8. How would you arrange the gears of an endless-rope haulage, the electric motor of which develops 100 h.p. at 960 r.p.m. whilst the fleeting pulley turns at 12 r.p.m.? State the types of gear that you would use. (*1st Class Exam.*, Nov., 1936.)

9. A sheave or grooved pulley, with shaft and bearings, is required for carrying a 1-in. diam. steel rope in a headgear over a vertical shaft. Draw up a specification to be sent to the makers when inviting tenders. Assume your own conditions, and include all dimensions and particulars likely to be useful.
(*1st Class Exam.*, May, 1937.)

10. A steel shaft is 4 ft. long and 7 in. in diameter. At one end there is a solid half-coupling 18 in. in diameter and 2 in. thick in the flange. At the other end there is a separate cast-steel half-coupling keyed on. This half-coupling is 20 in. in diameter, and 3 in. thick in the flange. The coupling flanges are plain. Make a side elevation of this assembly to a scale of 1½ in. to 1 ft., with dimensions, choosing your own dimensions where not given.
(*1st Class Exam.*, May, 1938.)

11. The teeth of gear wheels may have an *involute profile* and a *pressure angle* of 20°. Explain the terms in italic type and also what is meant by "circular pitch" and "diametral pitch."
(*1st Class Exam.*, Nov., 1938.)

CHAPTER VI

ELEMENTARY ELECTRICAL PRINCIPLES

Electro-Magnetic Induction. The principle of electro-magnetic induction discovered by Faraday, affirms that when a conductor is moved so as to cut magnetic lines of force, an electromotive force is induced in the conductor, and if the conductor forms part of a closed circuit a current of electricity will flow

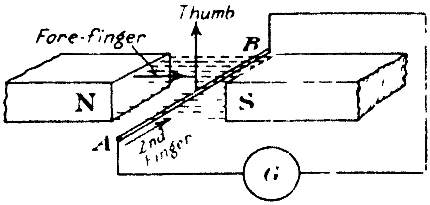


FIG. 50. ELECTRO-MAGNETIC INDUCTION

through it. The simplest mode of generating an electromotive force (E.M.F.) by magnetic induction is illustrated in Fig. 50. The conductor AB is placed in the magnetic field between the poles N and S and is connected to an external circuit in which there is a galvanometer G. If the conductor be moved upward through the field an E.M.F. will be induced in it, and current will flow in the direction of the arrow, the needle of the galvanometer being deflected to one side of the zero point, but if the conductor be moved downward the direction of the current will be reversed and the needle of the galvanometer will be deflected to the other side of the zero point. Should the conductor be moved along the lines of force, the latter would not be cut and no E.M.F. would be induced.

Magnitude of E.M.F. This depends on the combined influences of three factors: (1) the speed at which the conductor is moved; (2) the angle between the direction of motion of the conductor and the direction of the lines of force;

(3) the number of lines of force per unit of area, called the *flux density*. An important idea is that the E.M.F. induced in a conductor moving in a magnetic field depends on the rate at which magnetic lines of force are cut by the conductor. This is the principle upon which dynamo-electrical machines are constructed and operated, and the effect of such operation is capable of transmission to remote parts of coal mines for the utilization of power so transmitted.

Fleming's Right-hand Rule. The direction in which a current will flow in a conductor which is moved across a magnetic field in a certain direction can be readily determined if the thumb, forefinger, and second finger of the right hand be held mutually at right angles, with the thumb pointing in the direction of motion of the conductor and the forefinger pointing in the direction of the lines of force from N to S. The second finger will then point in the direction of the induced current. The converse of this rule may be applied to the electric motor if the left hand is used, for if a conductor lying in a magnetic field is carrying a current the conductor will be subject to a force which tends to move it in the direction determined by the directions of the current and the lines of force. Here is stated the simple principle of the electric motor.

Alternating Current in a Loop. Fig. 60 shows a rectangular loop of wire revolving in a magnetic field about an axis perpendicular to the lines of force. The rotary part of the simple dynamo, called the armature consists of two inductors *A* and *B* supported on a spindle *C*, and centred between the poles N and S of an electro-magnet. The ends of the loop are attached to two slip-rings S_1 and S_2, and the external circuit is connected to the ends of the loop by means of metal contacts or brushes bearing on the slip-rings, which are insulated from the spindle. If the rotation of the armature is considered to be clockwise, the application of the right-hand rule will show that the induced current passes round the loop and the external circuit, as the inductor *A* passes from its lowest to its highest position, in the direction of the arrows. When the inductor *B* passes in front of the N pole from its lowest to its highest

position the current will flow from front to back, in the opposite direction to that in which the current flowed while the inductor was passing in front of the S pole of electro-magnet. It is thus apparent that the current in the external circuit is an alternating one, and that the E.M.F. varies in

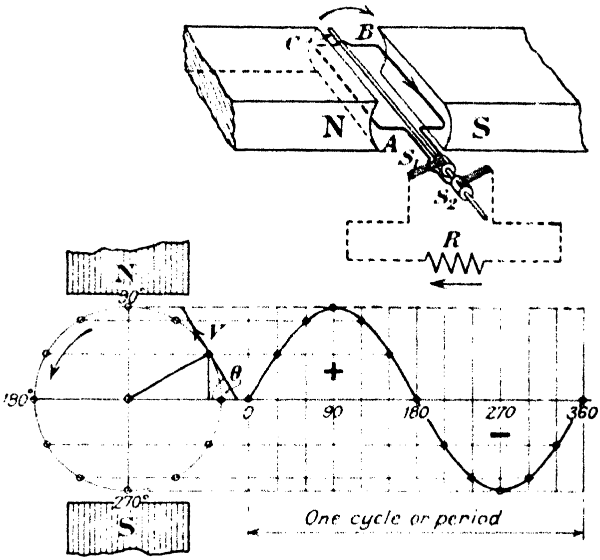


FIG. 60. A.C. IN A LOOP

magnitude and sign during the revolution of the loop. When the loop is passing through the vertical position the inductors are moving parallel to the lines of force, and therefore no E.M.F is induced, but when they are moving vertically, as the loop passes the middle of the poles, the lines of force are cut at the greatest rate, and consequently the E.M.F. is then a maximum. At any other instant when the angle between the direction of the inductors and the direction of the lines of force is θ it is clear that the vertical component of the velocity of the inductors must be $V \sin \theta$, hence the curve of E.M.F. is a simple sine curve which may be constructed graphically in the manner indicated in the lower portion of Fig. 60.

Equation of E.M.F. If an inductor of length l cuts across a magnetic field of flux density B at a velocity of v the E.M.F. induced in the inductor is Blv units (C.G.S.) or $Blv \times 10^{-8}$ volts, but as the rate at which lines of force are cut varies according to the sine law, the instantaneous value of the voltage is represented by $Blv \sin \theta \times 10^{-8}$ volts.

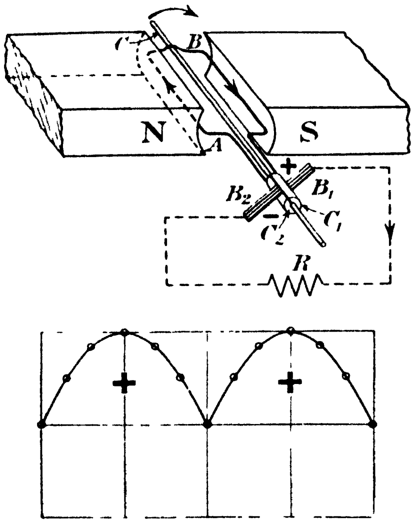


FIG. 61. COMMUTATION OF ALTERNATING CURRENT

Commutation of an Alternating Current. If instead of having insulated slip-rings attached to the ends of the loop, we have two semi-cylindrical commutator segments attached to the spindle, and insulated from it and from each other, as shown in Fig. 61, it is clear that the current in inductor A will pass from front to back. The current in inductor B will pass from back to front and enter the external circuit at the commutator segment C_1 and brush B_1. When inductor A has moved across the upper neutral position into the region of the pole S, the commutator segment C_2 will make contact with the brush B_1, and as the current in the inductor is passing from back to front to

commutator segment C_2, it is obvious that the induced current will enter the external circuit by the same brush (B_1) as before, hence the *alternating* current in the armature is rectified by the commutator so that the current in the external circuit is uni-directional or continuous. The variation of the E.M.F. across the brushes with the angular displacement of the loop from the vertical position between the poles is shown by the curve in the lower portion of the figure.

If another pair of inductors were attached to the spindle so that the plane of the loop formed by them made a right angle

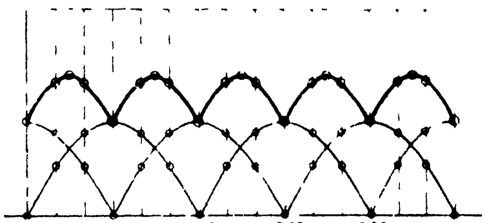


FIG. 62. RESULTANT E.M.F.

with the plane of the loop AB, and an additional pair of commutator segments were provided, the curve of E.M.F. would be displaced 90° from the curve shown in Fig. 61, but, as will be seen on referring to Fig. 62, the resultant E.M.F. would be the sum of the instantaneous values of the separate E.M.F.'s. The variations in the total E.M.F. are less pronounced than those in the original curve of E.M.F., and if we joined thirty such loops in series the E.M.F. would be practically free from fluctuations.

Ohm's Law. It is capable of experimental verification that the ratio of the voltage across the ends of a conductor to the current induced in the conductor is constant, provided the physical condition of the conductor does not change during the experiment. Ohm enunciated the law, known as Ohm's Law, thus: the current C induced in conductor of resistance R is proportional to the potential difference E across the ends of the conductor. Expressed in symbolic form, this becomes

$\frac{E}{C} = R$. The current C is measured in amperes, the potential difference in volts, and the resistance in ohms. In order to avoid confusion it may be observed that electromotive force is the term applied to that electrical force which, when applied to two points in a conductor, produces a potential difference (P D.) between them.

A Simple Circuit. Fig. 63 represents a simple circuit in which is shown a dynamo, a voltmeter, an ammeter, and lamps in parallel. It will be observed that the voltmeter is

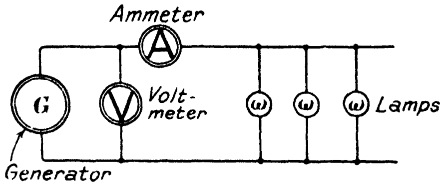


FIG. 63 A SIMPLE CIRCUIT

connected *across* the brushes and that the ammeter is connected in *series*. This arrangement is necessary to enable the P.D. across the brushes to be measured without taking current from the dynamo, and the current to be measured without interposing a great resistance in the path of the current. The current passes from the positive brush of the dynamo through the positive *lead* and ammeter, then through the lamps and back by the negative *lead* to the negative brush of the dynamo. In this circuit the total resistance is that due to the resistance of the leads plus the resistance of the lamps, the former being in *series* and the latter in *parallel*.

Specific Resistance. Materials used in electrical engineering may be divided into two classes: (1) those which are good conductors of electricity; (2) those which are bad conductors of electricity. The former are called conductors and the latter insulators. Silver, copper, and aluminium are good conductors of electricity, and porcelain, slate, vulcanite, and rubber are good insulators. In speaking of the resistance of a circuit it is

necessary to know the specific resistance of the materials composing the various parts of the circuit. The specific resistance of any material is that offered to the passage of current between opposite faces of a cube of unit length of edge. The specific resistance in ohms of a material may be referred to in terms of the centimetre^3 or the inch^3. For a conductor of given material at a constant temperature the resistance is proportional to the length and specific resistance, and inversely proportional to the area of cross-section, thus $R = \frac{\rho l}{a}$, where ρ is the specific resistance in ohms per centimetre cube, l the length of the conductor in centimetres, and a the area of cross-section in square centimetres. Since 1 in. equals 2·54 cm., and 1 sq. in. equals 6·45 sq. cm., the specific resistance in ohms per inch cube

$$= \frac{\text{specific resistance in ohms per centimetre cube} \times 2{\cdot}54}{6{\cdot}45},$$

hence, if the value of ρ for copper is $1{\cdot}592 \times 10^{-6}$ ohms per centimetre cube, the value per inch cube $= \frac{1{\cdot}592 \times 10^{-6} \times 2{\cdot}54}{6{\cdot}45}$ $= 0{\cdot}63 \times 10^{-6}$, and this at the temperature 0° C.

Example 29. Calculate the resistance of a copper wire 2000 yd. long and having a cross-sectional area of 0·1 sq. in.

Solution.

$$R = \frac{\rho l}{a} = \frac{1{\cdot}592 \times 10^{-6} \times 2{\cdot}54 \times 2000 \times 3 \times 12}{6{\cdot}45 \times 0{\cdot}1} = 0{\cdot}45 \text{ ohm.}$$

Example 30. Find the area of cross-section of a conductor 1500 yd. to transmit 250 amp. so that the total drop in volts along the conductor may not exceed 25.

By Ohm's law, the resistance of the conductor $= \frac{E}{I} = \frac{25}{250}$ $= 0{\cdot}1$ ohm, and as $R = \frac{\rho l}{a}$, we have $a = \frac{\rho l}{R}$

$$= \frac{1{\cdot}592 \times 2{\cdot}54 \times 1500 \times 3 \times 12}{6{\cdot}45 \times 10^{6} \times 0{\cdot}1} = 0{\cdot}33 \text{ sq. in.}$$

Variation of Resistance with Temperature. When a current of electricity is passed through a wire, heat is produced in the wire and the temperature and resistance of the wire may rise, hence the reason for specifying a limiting temperature rise in electrical apparatus. Given R_0, the resistance of a wire at $0°$ C.; $t°$ C, the rise in temperature, and a, the temperature coefficient of the material composing the wire, then the increase in resistance is R_0at, and the total resistance $= R_0 + R_0at = R_0(1 + at)$, or if $t_1°$ C. be the temperature of a wire whose resistance is known, and $t_2°$ C. is the temperature at an unknown resistance, the latter may be found by $R_2 = R_1 \ [1 + a(t_2 - t_1)\ ]$. The temperature coefficient of copper is 0·00428, and of aluminium 0·00423.

Resistances in Series. When an electric current flows through a number of resistances one after another, the resistances are said to be in series. Let r_1, r_2, and r_3 be resistances in series, and C the current flowing through them, then the drop in voltage across the resistances are by Ohm's law Cr_1, Cr_2, and Cr_3, and the sum $E = C(r_1 + r_2 + r_3)$, hence the total resistance $R = r_1 + r_2 + r_3$.

Resistances in Parallel. When an electric current is divided up so that each portion flows through a separate resistance, the resistances are said to be in parallel. In this case the voltage drop across the points to which the resistances are joined is E, therefore the current passing into the branches would be represented by $\frac{E}{r_1}$, $\frac{E}{r_2}$, and $\frac{E}{r_3}$, and the total current

$$C = \frac{E}{r_1} + \frac{E}{r_2} + \frac{E}{r_3} = E\left(\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}\right).$$ It is thus seen that the total resistance equals the quantity within the brackets, and if $r_1 = r_2 = r_3 = r$, it follows that $R = \frac{r}{3}$.

Example 31. Find the voltage required to send a current of 3 amp. through three resistances of 10, 15, and 20 ohms respectively when these are arranged (*a*) in series, (*b*) in parallel.

Solution.

(*a*) $E = C(r_1 + r_2 + r_3) = 3(10 + 15 + 20) = 135$ volts

(*b*) $E = \dfrac{C}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3}} = \dfrac{3}{\dfrac{1}{10} + \dfrac{1}{15} + \dfrac{1}{20}} = 13{\cdot}8$ volts

Example 32. The resistances of three circuits A, B, and C in parallel are respectively 10, 15, and 20 ohms, and the total current passing is 30 amp. Find the current in each circuit.

Solution.

$$\frac{\text{Current in } A}{\text{Total current}} = \frac{\dfrac{1}{r_1}}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3}} = \frac{\dfrac{1}{10}}{\dfrac{1}{10} + \dfrac{1}{15} + \dfrac{1}{20}} = \frac{1}{10} \times \frac{60}{13}$$

$$\therefore \text{ Current in } A = \frac{30 \times 60}{130} = \frac{1800}{130} = 13{\cdot}84 \text{ amp}$$

$$\frac{\text{Current in } B}{\text{Total current}} = \frac{\dfrac{1}{r_2}}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3}} = \frac{\dfrac{1}{15}}{\dfrac{13}{60}} = \frac{60}{195}$$

$$\therefore \text{ Current in } B = \frac{30 \times 60}{195} = \frac{1800}{195} = 9{\cdot}23 \text{ amp}$$

$$\frac{\text{Current in } C}{\text{Total current}} = \frac{\dfrac{1}{r_3}}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3}} = \frac{\dfrac{1}{20}}{\dfrac{13}{60}} = \frac{60}{260}$$

$$\therefore \text{ Current in } C = \frac{30 \times 60}{260} = \frac{1800}{260} = 6{\cdot}92 \text{ amp}$$

Ammeter. One of the effects of passing a current through a wire is to raise the temperature of the wire, and as the linear expansion of the wire is proportional to the increase in temperature, the heating effect of a current gives a ready means of measuring the current. Fig. 64 is a diagrammatic representation of a "hot-wire" ammeter. A thin platinum silver wire W is stretched between two terminals T_1 and T_2. Attached

at the middle of the wire there is another wire P of phosphor-bronze, which passes round a small drum D and is connected to a spring S. When current passes in the wire W it expands, but is kept extended by the action of the spring. The movement of the spring, or the extension of the wire, is communicated to the pointer which passes across a scale of amperes. From Ohm's law, $E = CR$, we get that $EC = C^2R$, hence the heat produced is proportional to the square of the current, and consequently the extension of the wire, and the movement of the pointer across the scale, is proportional to the square of the current. It is for this reason that the scale is unevenly divided.

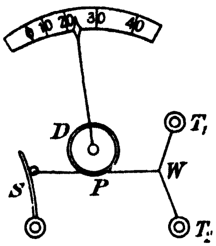


FIG. 64 HOT-WIRE AMMETER

The magnetic effect of a current may also be utilized in the construction of a "moving coil" ammeter. Fig. 65 shows a diagram of such an instrument. It consists of a coil of wire hung upon pivots between the N and S poles of a permanent magnet M. The movement of the coil about its axis is governed by a thin spiral spring at either end of the spindle. The effect of the springs is to return the pointer to zero when no current is passing, and they serve also to lead the current to and from the coil. A pointer P is attached to the spindle and moves with the coil. Since the coil lies in a magnetic field a torque must be applied to it when a current is passed through the instrument. The torque is proportional to the current and the strength of the field, but as the latter is constant the torque is proportional to the current, and the movement of the pointer across the scale is proportional to the current, hence the scale is evenly divided.

Owing to the fact that large currents may have to be measured with either form of ammeter, it is usual to place a low resistance shunt across the terminals, so that only a small but definite proportion of the whole current passes through the instrument.

Voltmeter. Since the P D between any two points in a circuit is proportional to the current flowing through a known resistance connected in series across those points, either of the hot-wire or moving-coil instruments may be used as a voltmeter The lower portions of Fig 65 show the low-resistance

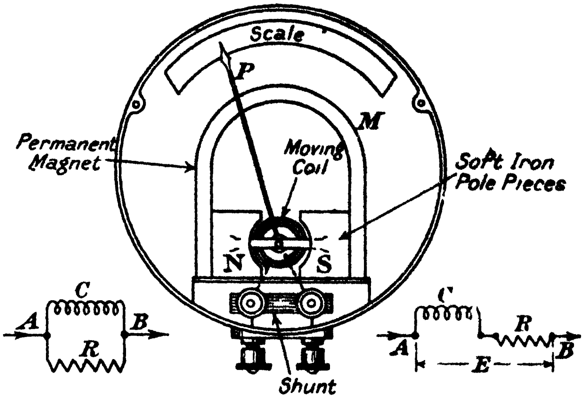


FIG 65 MOVING COIL VOLTMETER OR AMMETER

shunt for an ammeter and the high resistance series coil for a voltmeter

Example 33 The moving coil of an ammeter has a resistance of 1 ohm and the maximum current passing through it is 0 01 amp What must be the shunt resistance if the instrument is to read up to 100 amp ? What resistance must be placed in series with the coil when it is connected as a voltmeter across the terminals of a 200 volt supply ?

Answer. The P D across the coil in the first case $= CR = 0\cdot01 \times 1 = 0\cdot01$ volt, and the shunt resistance $R = \frac{E}{C} = \frac{0\cdot01}{100 - 0\cdot01} = \frac{1}{9999}$ ohm When the resistance is placed in series with the coil to enable the instrument to be used as a voltmeter, the total resistance must be $R + 1$, and as that $= \frac{E}{C} = \frac{200}{0\cdot01} = 20\,000$ ohms the series resistance $R = 19{,}999$ ohms

Power in a Circuit. Power is the rate at which work is done, and the electrical unit of power is the *watt*, which is the product of 1 volt by 1 amp., thus watts, $W = EC$, and 1 h.p. = 746 watts. In the measurement of power it is often convenient to use a larger unit, the kilowatt (kw.) and in reckoning cost of power the Board of Trade Unit, or kilowatt-hour, is used, thus B.O.T. units $= \dfrac{\text{watt-hours}}{1000}$.

Example 34. An electric motor is supplied with direct current at 500 volts, and it takes 72 amp. of current. Find the input horse-power of the motor and the total cost of the power consumed in 7 hr., if the cost of power per B O.T. unit is one penny.

Solution.

$$
\begin{aligned}
\text{Watts} &= EC = 500 \times 72 = 36{,}000 \\
\text{Kilowatts} &= \text{watts} \div 1000 = 36{,}000 \div 1000 = 36 \\
\text{B O.T. units} &= \text{kilowatt-hours} = 36 \times 7 = 252 \\
\text{Cost of power} &= \text{B.O.T units} \times \text{cost per unit} \\
&= 252 \times 1 = 252 \text{ pence} \\
&= £1\ 1s.
\end{aligned}
$$

Wattmeter. The power in a circuit is measured by a wattmeter, which is so constructed that the movement of the pointer is proportional to the product of the E.M.F. and the current. Fig. 66 shows two fixed coils C_1 and C_2 connected in series with each other and with the circuit, and a moving coil C_3 which is connected in series with the high-resistance R across the mains. A pointer P is attached to the moving coil, and it is capable of traversing a scale which is divided evenly. The movement of the pointer is proportional to the product of the current in the moving coil and strength of the field produced by the current in the fixed coils, and as the current in the moving coil is proportional to the E.M.F. and the strength of the field is proportional to the current in the mains, the pointer registers the product EC, the true watts. It is thus seen that the measurement of pressure and quantity is effected on the bases of effects of the current in a circuit.

Magnetic Effect of a Current. When a current of electricity is passed through a wire passing through a sheet of paper upon which iron filings have been sprinkled it is found that the

filings group themselves in chains, forming concentric circles around the wire with the wire at the centre of the circles. The arrangement of the filings in this order arises from the fact that the filings have been magnetized by the influence of the electric current, each magnet having its N and S poles, and the direction of the lines of force exhibited by the filings is definitely related to the direction of the current in the wire. If the current flows down through the wire it is assumed that the lines of force pass round the wire in clockwise direction, and that connection is signified by the "corkscrew rule." If a wire is arranged in the horizontal position over a magnetic needle and a current is sent through it from the S pole of the needle to the N pole, the latter will be deflected to the west, but it would be deflected to the east if the direction of the current was reversed. This is a useful test by which to determine the direction of the current in a wire; it is the principle of the *galvanoscope*.

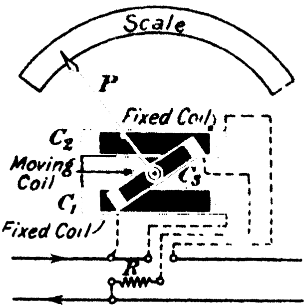


FIG. 66 WATTMETER

When a current is passed through a wire which has been wound in the form of a helix, a solenoid having N and S poles is formed. In Fig 67 the direction of the current through one of the turns of a helix is shown to take place from the cross to the dot, and if we apply the corkscrew rule we shall find that the magnetic lines of force pass in one direction through the solenoid from the S to the N pole.

Magnetic Circuit. The simplest case of a magnetic circuit is an iron ring of circular cross-section, as shown in Fig. 68. Suppose the ring to have a mean length of l centimetres, an area of cross-section of a square centimetres, and be wound with a magnetizing coil of T turns of wire. Then when a current of C amperes flows through the coil the magnetizing

force is given by $H = \frac{1 \cdot 25 CT}{l}$, and as the total *flux* N (magnetic lines of force) through the iron is given by the product of B (the flux per square centimetre) and a, and $B = \mu H$, where μ

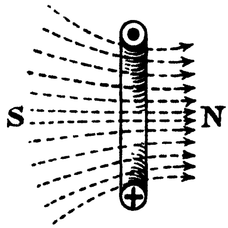


FIG. 67. SOLENOID

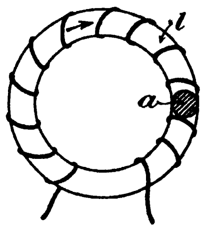


FIG. 68

is the permeability of the iron, we have $N = \mu H a = \frac{\mu 1 \cdot 25 CTa}{l}$

$$= \frac{1 \cdot 25 CT}{\frac{l}{a} \times \frac{1}{\mu}} = \frac{\text{magnetomotive force}}{\text{reluctance}}.$$

Example 35. An iron ring having a cross-sectional area of 3 sq. cm. and a mean circumference of 50 cm. is wound with 100 turns of wire. Find the number of lines of force (total flux) passing through the iron if the magnetizing current is 8 amp. and the permeability (μ) of the iron is 2000.

Solution.

$$\text{Total flux} = \frac{\mu \,.\, 1 \cdot 25 CTa}{l} = \frac{2000 \times 1 \cdot 25 \times 8 \times 100 \times 3}{50}$$

$= 120{,}000$ lines, or $40{,}000$ lines per sq. cm.

Since the value of μ for air is 1, we may profitably ascertain the flux through a ring in which there is a gap of, say, 0·2 of a centimetre,

$$\text{Total flux} = \frac{1 \cdot 25 CT}{\frac{l_1}{a_1 \mu_1} + \frac{l_2}{a_2 \mu_2}} = \frac{1 \cdot 25 \times 8 \times 100}{\frac{49 \cdot 8}{3 \times 2000} + \frac{0 \cdot 2}{3 \times 1}}$$

$= 13{,}351$ lines

The difference between these results may be interpreted as meaning that a greater number of ampere-turns (CT) would be required to produce the greater flux through the air-gap.

Electro-magnet. This may consist of a straight bar of soft iron, around which has been wound a wire through which may be passed an electric current. When a current is sent through the wire the bar of iron becomes magnetized, the N pole being that from which the magnetic lines of force emerge. This form of electro-magnet is used in the no-load and over-load releases attached to the controller of direct-current

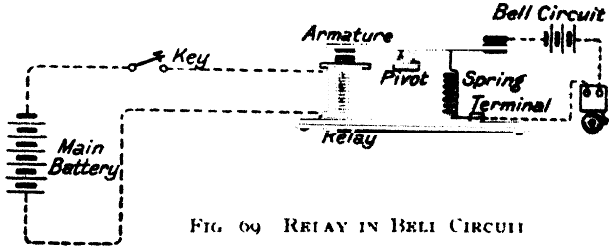


FIG. 69 RELAY IN BELL CIRCUIT

motors, and when it is made in the form of a horseshoe, it may be used to lift heavy weights or to actuate the armature of an electric bell.

Relay. When an electric current has passed over a long distance, as in underground signalling, the fall of potential may be such that the current at the remote end of the system may be incapable of performing useful work in actuating the armature of the bell, but as the magnetizing effect is proportional to the product of the amperes of current and the number of turns of wire on the solenoid, the solenoid of a relay may be wound so that the weak current in the line may be sufficient to operate the relay, and thus close the local circuit in which there is a battery of sufficient strength to operate the armature of the bell. Fig. 69 shows a relay in conjunction with a bell circuit.

Electric Bell. This device consists of an electro-magnet, one end of the coil of which is connected to the binding screw *A*, to which is also attached the wire from one of the "push" terminals. The other end of the coil is connected to the fixed end *B* of the armature, and the circuit is completed by a

spring C_2 and the wire passing from it through the other binding screw D to the battery E and the other side of the "push." When the circuit is closed by pressing the "push," a current flows round the electro-magnet, causing the armature to be attracted and the hammer H to strike the bell G. Since this movement of the armature breaks contact with the

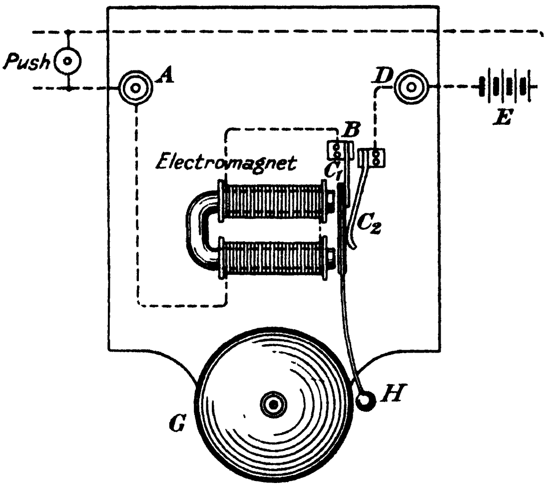


FIG. 70. ELECTRIC BELL

spring C_2, the current ceases to flow, the armature is demagnetized, and consequently the spring C_1, to which the latter is attached, is free to return to its original position in contact with the spring C_2. The current again flows through the coils of the electro-magnet, and the same cycle of events takes place with the result that the bell continues to ring so long as the "push" is pressed (See Fig. 70.)

Self-induction in Bell Circuits. Inspection of the gaps between the ends of the iron cores of an electro-magnet and the armature of an electric bell, whilst the bell is ringing, will reveal that bright and hot sparks, sufficient to ignite fire-damp, jump across the gaps.

That the sparks emitted are hot enough to ignite fire-damp

may be proved by placing the bell, or the ringing point on the wires, in an explosive mixture of methane and air. When an electric current is passed through a coil of wire surrounding an iron core a strong magnetic field is produced, and if the electric circuit be quickly broken the collapse of the magnetic field results in the establishment of an E.M.F. of self-induction, which causes the energy in the circuit to be dissipated in causing the current to pass across the air gap at the point where the circuit is broken.

It is obviously dangerous to have electric bells in fiery mines unless some means has been provided for reducing the energy of the sparks to such a point that they become incapable of igniting fire-damp.

Electric signalling bells may be made intrinsically safe by winding on to each bobbin of the electro-magnet an additional coil of copper wire, and bringing out the ends of the coil to two terminals which are joined by a short length of stout copper wire. There are thus in each intrinsically safe electric bell two short-circuited coils round which the self-induced currents are allowed to pass to dissipate the energy released on the breaking of the circuit by the withdrawal of the armature from the cores of the electro-magnets

Sparking is not prevented, but such sparking as does occur is incapable of igniting fire-damp. Such bells may be enclosed in a flame-proof case and be connected to ringing keys on haulage roads by means of bare wires, but flame-proof enclosure is not essential when sparking is non-incendive.

Chemical Production of an Electric Current. If pieces of any pair of the following substances, namely, zinc, cadmium, tin, lead, iron, nickel, bismuth, antimony, copper, silver, gold, platinum, and carbon, be taken and partially immersed in a dilute solution of sulphuric acid, a current of electricity will flow through the wire joining the substances from that which is named last to that which is named first; thus, if we were to use plates of carbon and zinc in this way the carbon plate would become the positive element and the zinc the negative. The Leclanché cell, which is much used in mining for signalling

purposes, has carbon and zinc elements. In the wet, or porous-pot, type of cell, the carbon rod with a mixture of carbon particles and manganese dioxide (MnO_2) are contained in a porous pot which is sealed with pitch except for a gas vent. The zinc rod is placed in the containing glass jar in a solution of sal-ammoniac (NH_4Cl). When the cell is working, zinc chloride, ammonia, and hydrogen are liberated, and the

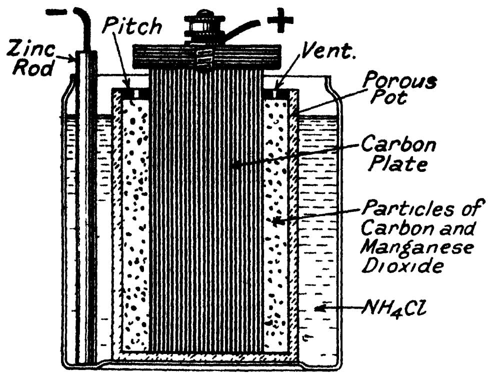


FIG. 71 LECLANCHÉ CELL

nascent hydrogen acts on the peroxide of manganese (MnO_2) to form the lower oxide Mn_2O_3. These reactions are represented as follows -

$$2NH_4Cl + Zn = ZnCl_2 + NH_3 + H_2$$

$$2MnO_2 + H_2 = Mn_2O_3 + H_2O.$$

Time is necessary for the complete reaction of the hydrogen with the manganese dioxide, and consequently the action of the cell is intermittent. In the intervals of rest between signals the cell recovers its strength and is eminently suitable for signalling work and telephony. The dry form of the cell is much used in telephony. Fig. 71 is a section of the wet Leclanché cell. At full strength the E.M.F. of the cell is about 1·6 volts.

Determination of the E.M.F. and Internal Resistance of a Cell. The E.M.F. of a cell may be determined by comparing it

with that of a standard cell by means of a quadrant electrometer. Fig. 72 shows the arrangement of the apparatus used in making such a determination. It is seen that one pair of quadrants is earthed, the other pair being arranged so that it may be charged by the cell at *C*. *D*, *E*, *F*, and *G* are pools of mercury in a block of paraffin wax. The quadrants *A* are connected to the mercury in *D* and the quadrants *B* to *F*. On placing a connector between *D* and *F*, the moving vane of the electrometer comes to rest at zero on the scale. The terminals of the standard cell are connected at *E* and *G*, and on removing the connector between *D* and *F*, and connecting *D* and *G* and *E* and *F*, the terminals of the cell are connected to the respective pairs of quadrants *A* and *B*, and thus a difference of potential is established between them. The deflection of the pointer is noted. The connectors are now made to join *D* and *E*, and *F* and *G*, and the deflection in the opposite direction is noted; the mean deflection is taken as the deflection for the standard cell. The same procedure is followed in testing the cell of unknown E.M.F., and the E.M.F. of cell under test is obtained by multiplying the E.M.F. of the standard cell by the deflection produced by the cell under test, and dividing by the deflection caused by the standard cell. Fig. 73 shows the arrangement of the apparatus that may be used to find the internal resistance of a cell. The apparatus consists of the cell to be tested, a tapping key K_1, a voltmeter *V*, an ammeter *A*, a plug key K_2, a variable resistance *R*, and the necessary connecting wire.

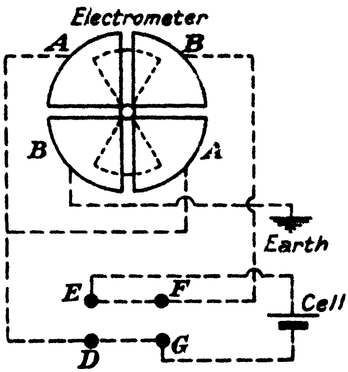


FIG. 72 QUADRANT ELECTROMETER

The E.M.F. of a cell is the potential difference (P.D.)

between its terminals on *open circuit,* and is indicated on the voltmeter when the key K_1 is used to close the circuit in which there is the cell, the key, and the voltmeter; but when K_1 is open and the plug is inserted in K_2, there is a current passing through the cell and the external circuit which includes K_2, A and R, the external variable resistance. When a cell supplies a current to a circuit the total resistance to the flow of the current consists of two parts, the internal resistance (r) and the external resistance (R), therefore the total resistance in the circuit is $R + r$. Ohm's law for a complete circuit states that the current $C = \frac{E}{R + r}$, or $E = CR + Cr$. The term CR represents the P.D. across the external resistance and may be called the external P.D.; similarly, the second term Cr may be called the internal P.D., hence the E.M.F. = external P.D. + internal P.D. In order that we may determine the value of r for any cell, we observe corresponding values of C, E, and R, so that by transposing the terms of the equation $E = CR + Cr$, we may get $r = \frac{E - CR}{C} = \frac{E - V}{C}$.

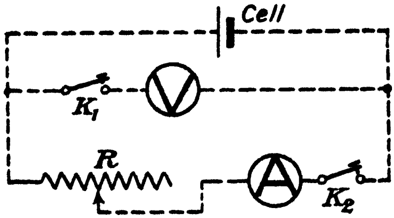


FIG. 73. CIRCUIT FOR FINDING INTERNAL RESISTANCE OF CELL.

To do this connect up the apparatus in the manner shown in the figure, having the whole of the available adjustable resistance in the circuit. Press the key K_1 and note the indication of the voltmeter. This is the E.M.F. of the cell, and it should be observed several times during the experiment, in order that the average value may be ascertained. Close the external circuit by inserting the plug K_2, and adjust the resistance R so that a small current C passes, as read by the ammeter. Press K_1 and note the reading of the voltmeter. It will be observed that the reading is now less than that obtained on open circuit. Repeat these observations for several values

of the resistance, and then tabulate the results as follows:—

E.M.F.	V	C	$r = \frac{E - V}{C}$
1·06	0·73	0·12	2·75 ohms
1·06	0·63	0·15	2·74 „
1·06	0·52	0·20	2·74 „
1·06	0·39	0·25	2·73 „
1·06	0·24	0·30	2·75 „
1·06	0·10	0·35	2·74 „

The average of the calculated values of the resistance of the cell is seen to be 2·74. The cell used in this test was a Daniell cell.

Secondary Batteries. These have long been used as a means of storing electrical energy, so that they might be used to drive motors when the generator normally applied to that purpose is temporarily out of use. Sometimes they are used to maintain a constant load on a generating plant, thus enabling a high efficiency to be obtained. They are not only used as the means of storing power by which winders may be driven, but they are used for the supply of power to the motors of underground locomotives, and they are finding an increasing field of usefulness in connection with miners' portable lamps. The storage batteries mostly used in mining work are of the Faure type, consisting of positive and negative plates, which are prepared by casting grids of pure lead to contain a large number of small pockets in which the active materials, in the form of a paste, are placed. The positive plates are made of grids in which the pockets have been filled with red oxide of lead mixed in sulphuric acid, so that by the reaction between them the following change takes place:—

$$PbO_3 + 2H_2SO_4 = PbO_2 + 2PbSO_4 + 2H_2O$$

The negative plates are pasted with monoxide of lead (PbO), or litharge, and sulphuric acid, which also reacts to form

$$PbO_2 + H_2SO_4 = PbSO_4 + H_2O$$

The pasted grids are placed in lead-lined boxes or celluloid cases, positive plates alternating with negative plates, and the positive and negative plates are connected to common terminals, which are distinctively marked. The cells are then filled to the tops of the plates with sulphuric acid, of specific gravity 1·195. The capacity of a cell is usually defined as the ampere-hours the cell will give before the E.M.F. falls to some arbitrary limit, which in practice is about 1·8 volts. Although the initial charging of a cell must be done slowly to allow the active material to " set," the normal rate of charging may vary from 0·5 to 2 amp. per sq. dm. of positive plate. The discharge current should not exceed 3 amp. As the voltage increases during charging from about 1·8 to 2·2, the density of the electrolyte (H_2SO_4) increases from about 1·195 to 1·220, therefore the amount of charge remaining in a cell may be ascertained by using a hydrometer to determine the specific gravity of the electrolyte

REFERENCE BOOKS

Electrical Engineering for Mining Students, by Harvey
Direct Current Electrical Engineering, by Barr
Electrical Technology, by Cotton
Elementary Electricity, by Starling
Mines Department Safety Pamphlet No. 8.

EXERCISE QUESTIONS

1. Describe an electromagnet. Name two types of electric plant used about collieries in which electromagnets are used.
(*2nd Class Exam* , May, 1920.)

2. A pump direct-coupled to an electric motor takes 175 brake horse-power to work it. The efficiency of the motor is 80 per cent. Electric power costs 1d. per Board of Trade unit at the motor terminals. What will it cost for power to run the pump for 8 hours ? (*1st Class Exam* , May, 1920)

3. Calculate the resistance of a copper wire 800 yd. long, and having a sectional area of 0·23 sq. in. Specific resistance of copper is $0{\cdot}63 \times 10^{-6}$ ohms per inch.

4. The output of a direct-current dynamo is 20 kw. The voltage is 440. What is the current ?
(*2nd Class Exam.*, Nov., 1919.)

5. In connection with electricity, what is meant by "insulation"? Name some of the materials used as insulators in connection with cables, motors, and bare copper transmission lines. (*2nd Class Exam.*, May, 1916.)

6. What are the names of the units of measurement most commonly employed in dealing with electricity, and their definitions? (*2nd Class Exam.*, Nov., 1920.)

7. What is likely to happen if two live copper conductors of a continuous circuit touch each other? What means are taken (*a*) to prevent this from happening, and (*b*) to lessen the evil consequences if it does happen? (*2nd Class Exam.*, May, 1919.)

8. What is a relay? Describe its construction and use, and state the principle of the instrument.

9. An electric signalling device is to be installed in a main haulage road 1000 yd. long, two wires being used. The resistance of the bell is 15 ohms and that of the wire is 7·5 ohms per 1000 yd. The E.M.F. of the cells to be used is 1·5 volts and the internal resistance is 2·2 ohms. Calculate the number of cells required and the current in circuit when the bell is ringing.

10. Describe the generation of an alternating current in a single loop, and draw the curves representing three such currents having a phase difference of 120° from 0° to 360°. What is the sum of the currents at any instant?

11. Describe how the alternating current in a simple loop is converted to a direct current in the external circuit, and draw a sketch to show the position of a voltmeter, an ammeter, and a wattmeter in such a circuit.

12. State the principles of construction of primary cells and secondary or storage batteries, and enumerate their respective uses about coal mines.

13. Three resistances have the values of 4, 6, and 8 ohms respectively. What would be the total resistance when they are connected (*a*) in series, (*b*) in parallel?

14. The current flowing in a main circuit amounts to 20 amp. What would be the current flowing in each of three branch circuits, arranged in parallel, if the resistances were 5, 10, and 15 ohms respectively?

15. Describe the construction of "hot-wire" and "moving-coil" voltmeters, and explain how a voltmeter may be arranged to serve as an ammeter.

16. Why should air gaps in dynamo electric machines be made as small as possible?

17. In connection with electrical power, what is meant by the terms: (*a*) ohm, (*b*) volt, (*c*) ampere, (*d*) watt? How are these four

units related in d.c. work? What is the unit of quantity of electricity? (*2nd Class Exam.*, Nov., 1931.)

18. What are the units of power and of energy or work (*a*) in mechanics, (*b*) in electrical work, and how are they related? A d.c. motor takes 50 amp. at 240 volts. What is the energy consumed in 6 hours in mechanical units? (*2nd Class Exam.*, Nov., 1934.)

19. Describe an installation of electric signals for an endless haulage system 2 miles long with junctions. Discuss the question of electric signalling, mentioning the available systems.

(*1st Class Exam.*, Nov., 1938.)

CHAPTER VII

DIRECT CURRENT PLANT

HAVING already discussed the production of a direct, or continuous, current by the rotation of a loop in a magnetic field and the method of producing such a field, we may now proceed to describe the salient features of the commercial continuous current generator. Any generator consists essentially of two main parts: (1) the field magnets; (2) the armature.

The former is usually stationary, whereas the latter is made to rotate, but it is only the circumstance of convenience that dictates that such an arrangement should be made.

Direct current generators or dynamos are similar in construction to motors and are capable of running as motors, just as motors may be made to run as generators.

Field Magnets. In small machines, such as magneto-exploders, the field magnets may be permanent magnets, that is, they may be made of steel so that once magnetized they retain their magnetism for a long period of time. The field magnets of dynamos are electromagnets which are excited separately from an outside source, or self-excited with current supplied by the armature of the machine itself. We have seen that the most efficient magnetic circuit is that in which the magnetic lines of force pass through some magnetic material such as iron or steel, but having regard to the fact that the armature of a dynamo runs between the field magnets, it is clear that there must of necessity be air gaps, and it follows an argument in the preceding chapter that the air gaps between the field magnets and the armature should be made as small as possible and that the inductors of the armature should be mounted on a core of iron. Fig. 74 represents in outline the yoke and field magnets of a six-pole machine and it is seen that the electromagnets are *wired* in

opposite directions so that N and S poles may alternate. Obviously, the number of poles must be even. Many modern continuous current dynamos and motors are fitted with smaller poles placed between the main poles. These are called *interpoles*, and are designed to enable the commutation of the current passing from the armature to the external

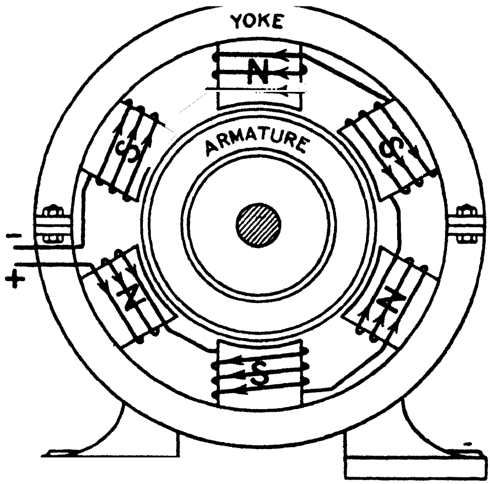


FIG. 74 YOKE AND FIELD MAGNETS

circuit to be effected with greater efficiency and less open sparking.

Self-excitation of Field Magnets. There are three general methods of exciting the field-magnets of dynamos, namely, by series excitation, shunt excitation, and compound excitation, and like methods may be used to excite the field magnets of motors. Fig. 75 shows that when the windings of the field magnets are in series with the external circuit, the whole of the armature current passes round the field windings; Fig. 76 shows that the field windings are in parallel with the external circuit, so that only a small part of the armature current passes round the field windings, and Fig. 77 represents a combination of series and shunt methods of excitation,

for the series windings are superimposed on the shunt windings.

When series excitation is used the flux in the armature varies with the current supplied by the armature, and if the machine runs at constant speed the E.M.F. generated varies with the current. The use of series excitation is therefore limited to generators working on a practically constant load, as in a lighting circuit.

A generator with shunt excitation on being started up produces but a small E M.F., because only a small part of

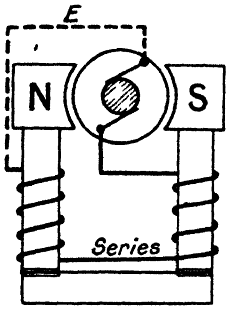


FIG. 75

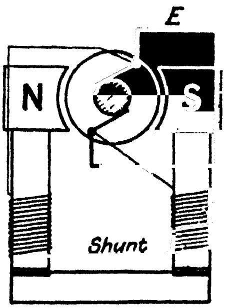


FIG. 76

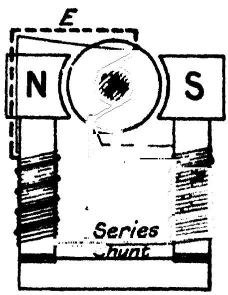


FIG. 77

the current is used to excite the field magnets, but as the E.M.F. increases so does the current flowing in the field windings, and as this increase in current produces a greater field flux the E.M.F. increases until the dynamo delivers current at the full rated voltage. Obviously, the voltage of the dynamo may be controlled by the adjustment of a variable resistance in the field winding.

If it is desired to maintain a constant terminal voltage across the brushes of a dynamo for all values of the armature current, the generator should have a compound winding in which the series and shunt effects are balanced. The need for this arrangement arises from the fact that the terminal voltage of a series-wound generator increases with increase of armature current, and the terminal voltage of the shunt generator drops as the armature current increases.

Armature. The construction of the armature of a dynamo, large or small, is based upon the necessity for providing an efficient magnetic path within the armature consistent with small air gaps and the minimum of leakage and eddy-current losses. The requisite magnetic path in the armature is provided by an iron core, and as eddy currents in the core flow at right angles to the direction of the field (in accordance with Lenz's law) the core of an armature is made up of thin discs of iron, each of which is insulated from its neighbours

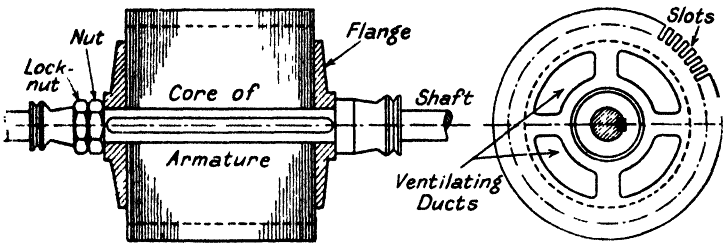


FIG. 78 ARMATURE CORE

by a thin layer of insulating material such as paper or varnish. These laminations are stamped out of sheets of annealed wrought iron or mild steel 0·5 to 0·6 mm. in thickness, and when varnished they are threaded directly on the shaft and held in position by a feather running along the length of the core. Fig. 78 shows the armature mounted on the shaft, being held in position between two flanges and secured in position by screwed collar and lock-nut.

It is always desirable that the laminations should be pierced to form ventilating tunnels so that the temperature of the armature may not rise unduly.

The armatures of large machines are built up in much the same manner, except that the laminations are stamped in segments, and the latter are provided with wedge-shaped lugs so that they can be dovetailed to the arms of the spider by which the armatures are attached to their shafts.

When the armature core has been built up, the inductors may be placed around the surface of the smooth core, but

the more usual arrangement is to place the inductors in slots that have been cut out lengthwise on the core

The inductors are placed in the slots in groups, being insulated from the core by presspahn 1 mm thick, and held firmly in position by a key of wood The majority of high-speed dynamos have semi-enclosed slots, as shown in Fig 79, the inductors being held in position by keys of beech wood The armatures of modern machines are of the drum type,

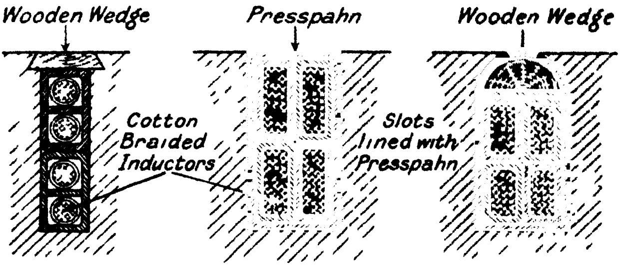


FIG. 79 INDUCTORS IN SLOTS

and the inductors are connected together to form two circuits, as in *wave-winding* [1] or in multiple circuit as in *lap winding*

E.M.F. of a Dynamo. The absolute unit of pressure is that generated in an inductor cutting one line of force per second This definition enables us to express the E M F of a dynamo in terms of the armature winding armature speed, number of poles and the flux per pole cut by the armature inductors

The E M F induced in a single inductor of length l moving with a velocity v across a field in which the flux density is B is $Blv \times 10^{-8}$ volts Let Z be the number of inductors between the brushes of a 2 pole dynamo, then the E M F generated if the armature makes n revolutions per second is expressed as

$$\text{E M F} = \frac{Blv}{10^8} \times \frac{Z}{2} \times \frac{\text{pole arc}}{\text{pole pitch}}$$

[1] See *Direct Current Electrical Engineering* by Barr (Pitman)

$$= \frac{B \times l \times 2\pi r n}{10^8} \times \frac{Z}{2} \times \frac{\text{pole arc}}{\pi r}$$

$$= \frac{Bl \times \text{pole arc}}{10^8} \times \frac{nZ}{1} = \frac{\phi Z n}{10^8} \text{ volts,}$$

where ϕ is the flux per pole, having regard to the convenience of referring to the speed of rotation in revolutions per minute, we may give the expression the form—

$$\text{E.M.F.} = \frac{\phi Z N}{60 \times 10^8} \text{ volts.}$$

This expression applies to a lap-wound having any number of poles, but if a problem relates to a wave-wound machine in which there are two circuits, we must multiply the expression by $\frac{p}{2}$, the number of pairs of poles.

Example 36. A six-pole dynamo running at 250 r.p.m. has a lap-wound armature having 160 slots and six inductors in each slot. If the flux per pole is 5,000,000 lines, find the voltage generated by the dynamo

Solution.

$$\text{E.M.F.} = \frac{\phi Z N}{60 \times 10^8} = \frac{5 \times 10^6 \times 160 \times 6 \times 250}{60 \times 10^8} = 200 \text{ volts.}$$

Wave winding is embodied in machines of low output and high speed, and lap winding is used in machines designed to give a large output at low speed

Commutator. The commutator is the means provided for the passage and rectification of the currents from the armature to the external circuit. It is built up of the requisite number of sections consisting of bars of hard-drawn copper, each section being insulated from the other by thin sheets of mica, the whole being held in position on a gun-metal sleeve by means of wedge-shaped circular rings at each end. Fig. 80 shows the construction of a commutator such as might be used for a dynamo of 500–1400 kw. In commutators of this size the clamping rings, sometimes built in sections, are

bolted to the spider. This construction enables a faulty segment to be removed without disturbing the rest of the commutator. The figure also shows the lug *L* by which the inductors are connected to commutator segments by brazing or soldering.

Brush Gear. The brushes used for collecting the current from the commutator were formerly made of metal gauze

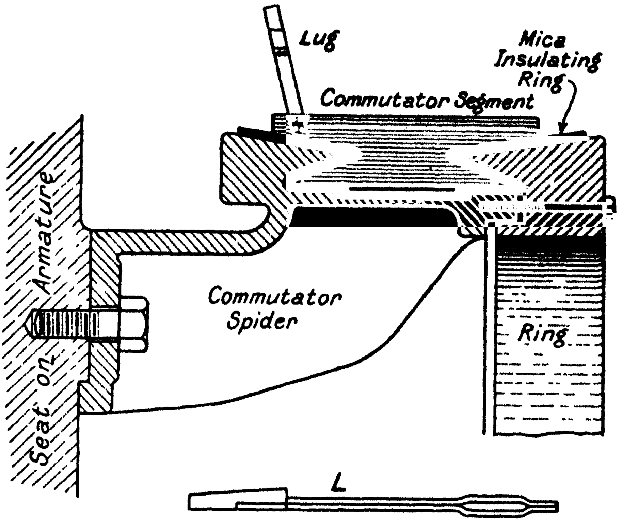


FIG. 80 SECTION OF COMMUTATOR

but now they are made of hard blocks of graphitic carbon. Carbon wears well mechanically and carbon brushes impart to the commutator a tough, glossy surface, offering but little resistance to the passage of the surfaces in contact. Metal brushes are sometimes used for turbo-generators in which the speed of rotation is very high. A double set of brushes is required for each pair of poles.

The brushes are held in holders of the *hammer* or *box* types, and the holders are attached to brush rockers which are fitted to a cast-iron ring mounted concentrically with the commutator. Besides supporting the brush, the brush-holder

has also to press firmly on the commutator, and at the same time give sufficient flexibility to enable it to ride over any slight eccentricity of the commutator without reducing the efficiency of commutation.

Commutation. The correct position for the brushes when the armature is carrying only very small currents is such that they are always connected to conductors lying in the neutral

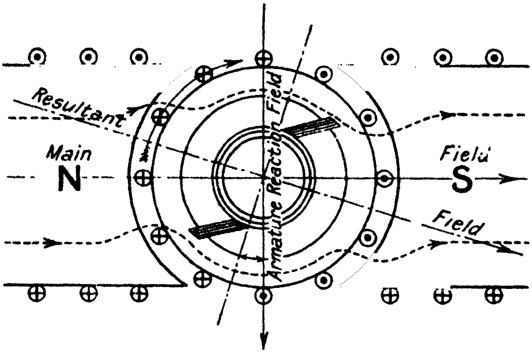


FIG. 81 ARMATURE REACTION

zone between the poles, where they have no E.M.F. induced in them, but should the armature be carrying large currents there is another field produced having its lines at right angles to the direction of the main field, and consequently the resultant field makes a varying angle with the direction of the main field. The resultant effect is that the brushes placed in the normal position will be carrying current, and if left in that position commutation would be accompanied by sparking. To avoid this effect of *armature reaction* the brushes must be moved forward to the position shown by the dotted line in Fig. 81. Sparking may still continue to take place with the brushes in this position, but interpoles[1] may be used to counteract armature reaction and thus enable commutation to take place without sparking.

Methods of Driving a Dynamo. Direct-current generators

[1] *Electrical Engineering for Mining Students*, by G. M. Harvey (Pitman)

are almost invariably driven through speed reduction gear. When a reciprocating engine is used to drive a dynamo it will usually be necessary to provide a rope or belt drive for the purpose of causing the armature to rotate at a greater speed than the crankshaft of the engine, but should a turbine be used to drive the generator it might be necessary to reduce the speed of rotation from 5 to 1 or 7 to 1 by the introduction of toothed gear of the double helical type running in oil. High-speed engines of the Belliss and Morcom vertical type may also be used when it is desirable that high-pressure steam should be utilized for that purpose.

Paralleling of Dynamos. Series wound machines are unsuitable for running in parallel, but shunt and compound-wound machines may be run in parallel when it is desired to supply power to a constant potential circuit from more than one dynamo. When it is desired to run one shunt-wound dynamo in parallel with another already supplying power to a circuit the incoming machine is run up to its speed with the main switch open, and when the voltage has been adjusted by a regulator in the shunt windings the main switch is closed and the shunt resistance removed. A reverse cut-out switch is placed between the positive bus-bar and each of the machines to prevent either running as a motor. When compound-wound machines are run in parallel the risk of one running as a motor is prevented by arranging the series coils in parallel by means of an equalizing bar and switches, and the equalizing switch must be closed before the incoming machine is started up, just as it must remain closed until the machine has been taken out again.

Switchboard. A switchboard suitable for a colliery installation generating direct current is usually divided into three main sections: (1) the generator panel; (2) the lighting panel; (3) the power panel. Should there be two generators installed, there must also be two corresponding panels, there must be one lighting panel, and as many feeder panels as there are power circuits. A total output meter may be placed on the lighting panel. Fig. 82 shows the wiring

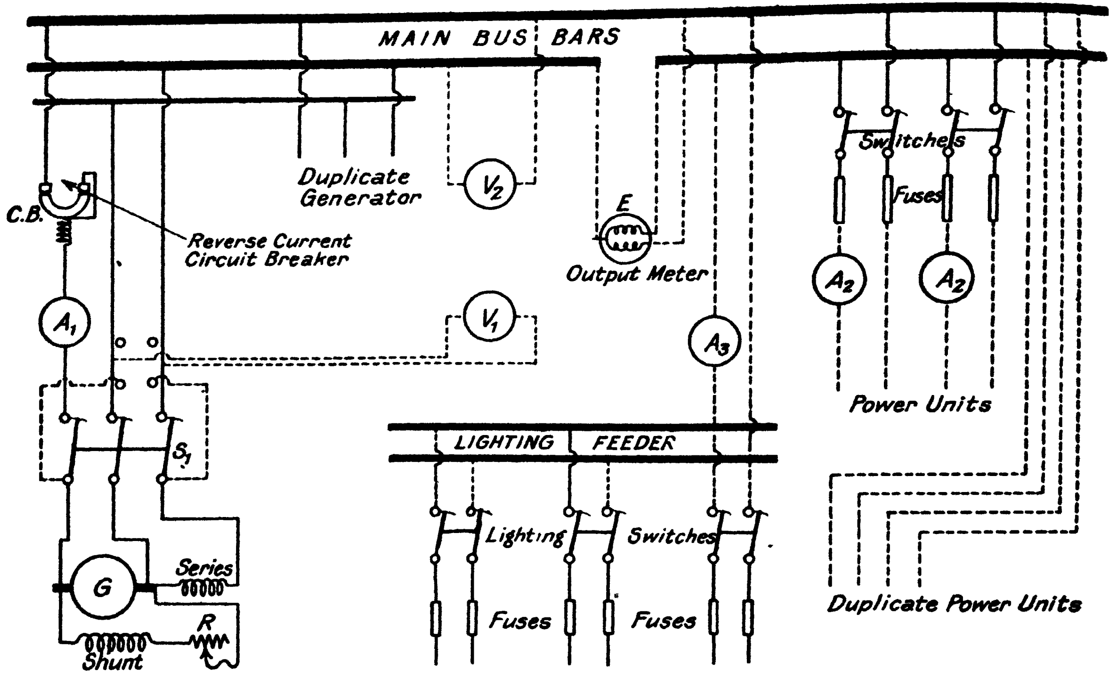
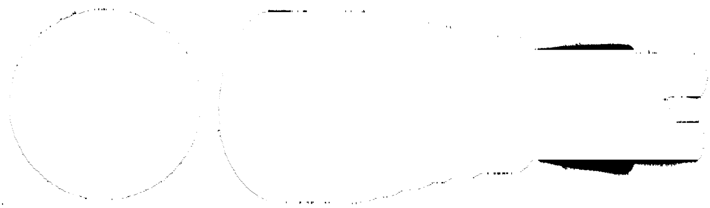


FIG 82. WIRING FOR D.C. POWER AND LIGHTING SWITCHBOARD

of a power and lighting switchboard suitable for a colliery installation having a capacity of 500 kw.

Transmission of Direct Current. It is necessary to provide two paths for the transmission of power by direct current, and for that reason the cables used have two conductors embodied in them, and they may also have a third wire to form the connection between the various machines and appliances that must be earthed (see *Mines and Quarries*, Form No. 11) and the main earthing system on the surface of the mine. Cables



(W. T. Glover & Co., Ltd.)

FIG. 83 "SOLBIT" CRACORE CABLE

may be divided into three classes, viz., shaft cables, road cables, and trailing cables. All cables must be efficiently protected from mechanical damage, and shall be supported at sufficiently frequent intervals and in such a manner as adequately to prevent *danger* and damage to the cables.

Shaft Cables. The shaft cables have to carry all the current passing into the mine and consequently they are of large copper section, and since they are heavy they must be substantially made. The separate strands of the cable are usually tinned and covered with high-grade rubber insulation, and these are laid in a specially shaped cradle-core and surrounded by bitumen. To further strengthen the cable it is given two servings of braid and double-wire armoured, the wires being wound in opposite directions. This construction gives the strength necessary to carry the weight of the cable suspended in the shaft, and an outer covering of fibre is provided so that

the cable may be given a coating of pitch or Stockholm tar to exclude moisture from the insulating material. Fig. 83 shows a Glover Cracore cable.

A convenient method of lowering a cable into the shaft is to place it on a reel adjacent to the mouth of the shaft

(*W. T Glover & Co., Ltd.*)

FIG. 84 SPLITTING CLEAT FOR SUPPORTING CABLE IN SHAFT

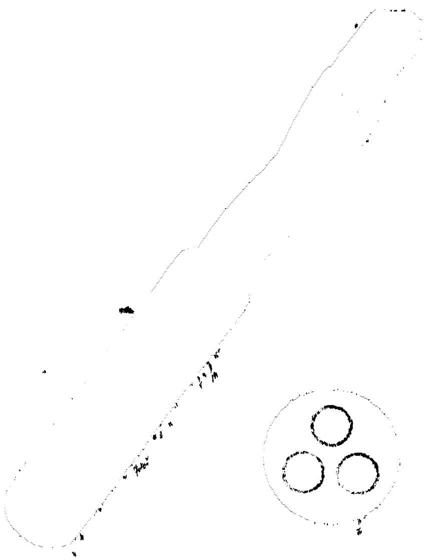
and pay off the cable into the shaft, lashing the cable at intervals to a crane rope with pieces of white rope, each lashing being arranged to carry about 1 cwt. of cable. Obviously, the reel and crane would have to be provided with efficient brakes to control the descent of the cable. When the shaft is deep it may be necessary to install the cable in sections which are joined together by junction-boxes designed

for that purpose. The cable is supported in the shaft by means of cleats made of red pine 9 in. wide and 3 in. thick. A cleat of the sitting type is shown in Fig. 84, the height being 3 ft. In fixing the cable in the cleat it should be wrapped in brattice cloth, or old rubber hose, to give a good grip and to protect the insulation within the cleat.

Road Cables. Since these are usually branches from the main cable, they are of lighter construction and may be protected by a metallic covering in accordance with General Regulation 129. Obviously, the nature of the protection of a cable and the method of supporting it must depend on the construction of the cable and the condition of the roof and sides in the road in which the cable is placed In roadways of sufficient width armoured cables are sometimes laid on the floor at the side of the road and covered with troughing, but they may be suspended by slings of braid or leather attached to props, or other roof supports. Cables unprotected by a metallic covering shall be properly secured by some non-conducting and readily breakable material to efficient insulator [G.R. 129 (*d*)].

Trailing Cables. These cables must of necessity be very flexible and possessed of considerable mechanical strength to resist abrasion of the insulating material, and the insulating material used should be such as to prevent the access of moisture to the cores of the cable. Several classes of cable are used for this purpose, the various constructions being: (1) vulcanized rubber insulation, with armouring of galvanized iron wire; (2) vulcanized rubber insulation, covered with braiding of leather; (3) vulcanized rubber insulation, with covering of cord braiding; (4) vulcanized rubber insulation, with cab-tyre sheathing. Our experience with different kinds of trailing cables leads to the conclusion that the last mentioned cable, the construction of which is shown in Fig. 85, is by far the most satisfactory. The trailing cable embodies an earth wire which is connected to the main earthing system at the gate-end box, so that the danger of shock to persons handling the portable machine fed by the cable may be minimized.

Size of Cable. The size of a cable, or area of copper section, is determined by the power to be transmitted and the allowable loss in transmission, and the number of wires constituting the cores is dependent on the degree of flexibility that must be possessed by the cable. Shaft and road cables need not be



(W. T. Glover & Co., Ltd.)

FIG. 85 CAB-TYRE TRAILING CABLE

so flexible as trailing cables and, therefore, the number of wires for a given copper section is usually less in the former than in the latter. The usual method of ascertaining the construction of a suitable cable is to calculate the copper section and refer to cable tables for choice of cable. At least two of different flexibility will be available.

Example 37. The input horse-power to a cable 1000 yd long is 120 h.p., the voltage being 450. Given that the specific resistance of copper is 0·66 microhm per inch cube, and that the permissible drop in power in the line must not exceed 7 per cent, find the area of cross-section of the leads.

Solution.

Input watts	$= 120 \times 746 = 89{,}520$
Output watts	$= 0{\cdot}9 \times 89{,}520 = 80{,}568$
Watts lost	$= 89{,}520 - 80{,}568 = 8952$
Total current	$= \dfrac{\text{watts}}{\text{volts}} = \dfrac{89{,}520}{450} = 199{\cdot}2$ amp.
Voltage drop	$= \dfrac{\text{watts lost}}{\text{current}} = \dfrac{8952}{199{\cdot}2} = 45$
Resistance of cable	$= \dfrac{E}{C} = \dfrac{45}{199{\cdot}2} = 0{\cdot}226$ ohm.
Area of cable	$= \dfrac{Pl}{R} = \dfrac{0{\cdot}66 \times 10^{-6} \times 1000 \times 3 \times 12}{0{\cdot}226}$
	$= 0{\cdot}105$ sq. in.

On referring to standard cable tables it is found that either a 19/11 or a 61/16 cable might be used for this case, the latter being the more flexible since it has almost the same section of copper and has 61 wires instead of 19 of greater gauge.

Direct Current Motor. We have followed the conversion of mechanical energy to electrical energy and the transmission of the latter to the remote ends of cables supplying electric motors by which it is converted from electrical energy to mechanical energy. The construction of the electric motor is essentially the same as that of a dynamo, and therefore any reliable dynamo will also function as a motor, when it is supplied with power from a dynamo. When a motor is supplied with power from an external source (a dynamo or a storage battery), the armature rotates in the magnetic field between opposite poles of the electromagnets. This rotation of the conductors of the armature within the magnetic field causes the induction of an E.M.F., which tends to oppose the influence of the applied E.M.F., and thus the current in the armature is proportionately reduced. The back E.M.F. of the motor at the instant of starting is zero, and consequently the current passing through the armature conductors is a maximum, but as the speed of the armature increases so does the back E.M.F. increase until the current in the armature

conductors is a minimum. This explains why a motor takes current in proportion to the work to be done, and, incidentally, it shows the need for some protective device which would come into operation automatically should the load be unduly great. One method of limiting the current is by the insertion of fuses in the mains leading to the motor and another consists of an "overload release," or circuit-breaker, attached to the controller, the latter being an essential part of the equipment by which the initial flow of current is limited.

The back E.M.F. may be calculated by the formula given earlier in this chapter, thus

Back E.M.F. $= \dfrac{\phi Z N}{60 \times 10^8}$ (multiplied by $\dfrac{p}{2}$ for wave winding),

and the current in the conductors is proportional to the difference between the applied E.M.F. and the back E.M.F., thus $C = (E - e)/R$.

Example 38 A 30 h.p. motor has a wave-wound armature in which there are 420 conductors, the resistance of the armature being 0·39 ohm Calculate the speed at which the motor will run when connected to a 400-volt supply, if the flux per pole is 6×10^6 lines, and the machine has six poles.

Solution.

$$\text{Input watts} = 30 \times 746 = 22{,}380$$

$$\text{Current} = \frac{\text{watts}}{\text{volts}} = \frac{22{,}380}{400} = 56 \text{ amp}$$

$$\text{Back E.M.F.} = E - CR = 400 - 56 \times 0{\cdot}39 = 378 \text{ volts}$$

$$N = \frac{60 \times 10^8 \times 2 \text{ back E.M.F.}}{\phi Z p}$$

$$= \frac{60 \times 10^8 \times 2 \times 378}{6 \times 10^6 \times 420 \times 6} = 300 \text{ r.p.m}$$

Deductions of Practical Importance. Examining the foregoing formula for motor speed, it is observed that Z and p are constants, and consequently the formula may be given the form

$$N = \frac{K(E - CR)}{\phi}$$

Since N is inversely proportional to ϕ, it follows that if ϕ the field flux be suddenly interrupted the speed of rotation N would immediately increase, and the speed might become so great as to wreck the motor by the bursting of the armature. Such an occurrence may be prevented by "making the field circuit first and breaking it last."

The field flux depends on the armature current, hence in the case of a series wound motor any increase in the value of C results in the decrease of $E - CR$ and an increase in the value of ϕ, and consequently the value of N decreases. But the converse is equally true and of much greater importance for should the motor lose its load suddenly, as it might if the rope of a direct haulage broke with a gang of tubs on a steep grade, the motor would race and probably suffer damage. Here we have an explanation of the advantage of a series motor for such work as main-rope haulage or coal-cutting, for the greater the load the less the speed and the greater the power of the motor, as represented by the increasing value of C. To prevent this it is usual to steady the action of the series motor by the winding of a few turns of shunt wire on the field magnets. By adjusting the series and shunt windings of a compound-wound motor, the value of $E - CR$ may be adjusted with respect to that of ϕ, so that the value of N may be made practically constant at all loads. This type of motor is more widely used for mining work than either of the other two types, because it embodies the salient features of both without having their disadvantages.

Rating of Motors. Motors are rated for continuous working and for intermittent working, that is, they should be capable of developing the power for which they were designed for a certain period of time without the temperature rising by more than 40° C. For continuous rating the running period is usually six hours, but for intermittent rating the period may be one hour or two hours, during which the motor is run on full load. Since, in the latter case, the motor will have time to cool during intervals of rest, a smaller motor may be used for a given duty than would be necessary for continuous rating.

Motors used to drive pumps, fans, endless rope haulages, and other continuous running plant should be continuously rated, but motors taking intermittent loads as in winding and haulage by main or main and tail rope should be rated on the short period. Starting resistances are similarly rated. Since the rating affects the size of a motor to which may be assigned a given duty, it is obvious that the type of enclosure of the motor must also affect the size. Enclosed motors are always

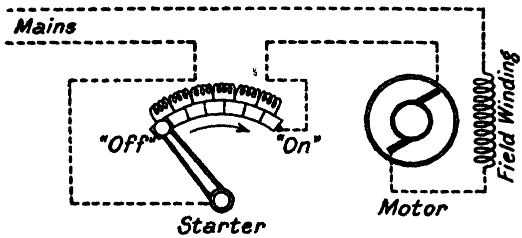


FIG 86 CONTROLLER FOR SERIES MOTOR

larger than motors of the open type in which there may be rapid transference of heat to the surrounding air.

Losses in Motors. These may be summarized as follows—

1. Frictional resistance of bearings and brushes.

2. Windage, due to fanning action of rotating parts.

3. Excitation loss, due to power required to produce magnetic field.

4. Copper loss, due to resistance of armature and field coils.

5. Iron loss, due to eddy currents and hysteresis.

Motor Controllers. The controller used for starting a series motor consists of a number of resistances in series, each resistance being connected to a stud on the resistance panel. These studs are arranged on the arc of circle, so that the controlling switch may be turned from the " off " position across the studs to the " on " position, as shown in Fig. 86. No provision is made for automatically returning the switch handle to the " off " position on cessation of the current. The connections for a shunt motor controller are shown in

Fig. 87, and it is seen that there is an "overload" release in the armature circuit and a "no-voltage" release in the field circuit. In starting the motor the switch is turned from "off" across the studs to "on," in which position the handle is held by the electromagnet *NVR*. Should the field be interrupted the handle would be released by the "no-voltage" release, and the handle would be returned to the off position by the spring pivoted at the spindle upon which the handle is

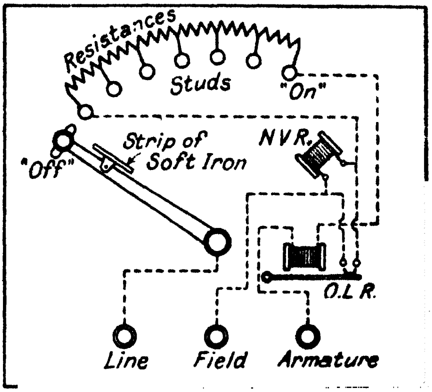


FIG. 87 SHUNT MOTOR STARTER

mounted. On the other hand, should the load become excessive and the armature current rise too high the "overload" release (*OLR*) would operate to short-circuit the "no-voltage" release, and thus allow the handle to return to "off." The same type of controller may be used for compound wound motors, but speed variation may be obtained by the use of shunt rheostat. The resistance elements of a controller are usually made of an alloy such as manganin, which has a specific resistance of $42{\cdot}92 \times 10^{-6}$ ohms per centimetre cube at 0° C., and the whole is assembled in the form which is most suitable to the circumstances in which motors are used. Obviously, the controller of a coal-cutter might have to be made so that the motor would be reversible, and it would have to be designed to occupy a comparatively small space

possibly of peculiar shape. Fig. 88 shows the construction of a liquid starting resistance such as is used in colliery work. The body consists of a cast-iron trough *A* which contains a solution of caustic soda or sal-ammoniac (NH_4Cl). *Pivoted at the point B there is an iron plate C which dips into the* liquid. The pivot is insulated from the trough, and the lead to which it is connected is insulated by a porcelain insulator. The other lead is electrically, and therefore

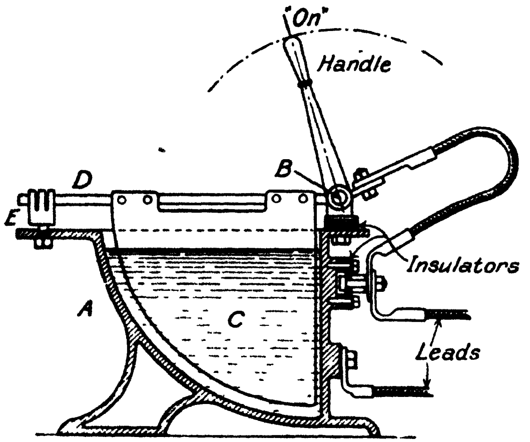


FIG. 88. LIQUID STARTER

mechanically, connected to the body, so that when the plate *C* is dipped into the liquid the resistance opposed to the flow of current is inversely proportional to the wetted area of the plate. As the plate is lowered the resistance offered by the liquid is gradually decreased until, finally, the current is short circuited by the arm *D* of the blade engaging with the contact *E* on the body of the trough.

Efficiency of Motors. The mechanical efficiency of an electric motor may be expressed as the ratio of the output horse-power to the input horse-power. The output horse-power can be calculated from the results of dynamometer tests and the input horse-power from readings of a voltmeter and an ammeter, or a watt-meter. In the course of the

experimental work carried out by mining students the opportunity is usually taken to study the characteristics of motors while investigating the efficiency of such machines on different loads, and no other method of studying the peculiarities of motors is so impressive as the practical one

The experiments are designed to enable the speed (N) in r.p.m., the current (C) in amperes, the dynamometer weights W_1 and W_2, corresponding to different loads with a constant applied voltage (E) to be observed, so that the mechanical efficiencies at different loads may be computed, thus—

1 Input watts $= CE$, and input horse-power $= \dfrac{CE}{746}$

2. Torque $= T = (W_1 - W_2)\left(\dfrac{d + t}{2}\right)$, where d = diameter of brake pulley, and t is the thickness of rope in feet

3 Output horse-power $= \dfrac{2\pi NT}{33{,}000}$

4 Efficiency of motor $= \dfrac{\text{output h p}}{\text{input h p}} = \dfrac{2\pi NT \times 746}{33{,}000\ CE}$

The small motors used in mining laboratories can be mounted on ball bearings so that the yoke and field magnets are pivoted on the armature shaft, thus enabling the torque to be determined by taking the product of a weight (W) and its distance (d) from the centre of the bearing on a balanced arm attached to the yoke

REFERENCE BOOKS

Colliery Electrical Engineering, by Harvey (Pitman)
Electrical Practice in Collieries, by Prof Burns
Mining Electrician's Handbook, by Lokes
Direct Current Electrical Engineering, by Barr (Pitman)

PAPERS

Transactions of the Association of Mining Electrical Engineers.
Transactions of the Institution of Mining Engineers

EXERCISE QUESTIONS

1. In electrical plant what are the differences between a dynamo and a motor? How are motors started?

(*2nd Class Exam*, *Nov.*, 1917)

2. The output of a direct current dynamo is 20 kW. The voltage is 440. What is the current?

(*2nd Class Exam., Nov.,1919.*)

3. Electricity: Units of Measurement. What are the units most commonly employed in dealing with electricity, and their definitions? (*2nd Class Exam., Nov., 1920.*)

4. Describe the most suitable apparatus for controlling, safeguarding and starting up a continuous current motor of 250 h.p., using high-tension current, to comply with the electrical rules

(*2nd Class Exam., Oct., 1921.*)

5. Electric motors may be " series wound," " shunt wound," or " compound wound." Explain these terms and state why the various types of winding are adopted

(*2nd Class Exam, May, 1922.*)

6. Give a description of a direct-current generator (or dynamo) arranged to be driven by a belt, and explain how the generator works and supplies current to the mains.

(*2nd Class Exam., Nov., 1922.*)

7. Describe the electric plant usually to be found in a house underground of a main- and tail-haulage gear worked electrically. You may assume the current to be direct or alternating.

(*2nd Class Exam., May, 1923.*)

8. Describe an electric cable for carrying continuous current at 440 volts down a wet shaft. (*2nd Class Exam., Nov., 1918*)

9. In connection with electrical plant, what is meant by earthing? An electric coal-cutting machine has a frame with gear box and chain, and a motor with frame, field cores, armature windings, commutator, field windings, and shaft. Which of these parts should be earthed, and for what reason?

(*2nd Class Exam., May, 1925.*)

10. Describe shortly two devices adopted for preventing the passage of too high currents through electrical circuits.

(*2nd Class Exam., Nov., 1913.*)

11. Describe the construction of the armature of a D.C. generator, state the effect of armature reaction on the position of the brushes.

12. What do you understand by the back E.M.F. of a motor?

13. Why does an electric motor require a starting resistance in the circuit? Explain the action of a shunt rheostat, and state the functions of the overload and no-volt releases.

14. Why is it advisable that two generators should be provided to supply current for power and lighting at a colliery? Describe how dynamos are run in parallel.

15. Draw a sketch to show the form of a junction box suitable

for joining an armoured twin cable, and explain how the armouring is connected to the box to ensure continuity of the earthing conductor.

16. What modifications must be made in the connections of series, shunt, and compound-wound dynamos to enable them to run as motors ?

17. Draw a circuit diagram to show how you would connect up a shunt motor for the purpose of testing it with a balanced-torque dynamometer, and state the relation between b.h.p. and e.h.p. in terms of observed quantities.

18. Describe an efficient earthing system such as would comply with the special electricity rules relating to coal mines.

19. Describe a switchgear suitable for controlling a coal-cutting machine circuit and for placing in a road near the coal face. Choose either a d c. or a three-phase system, stating which you adopt. (*2nd Class Exam.*, *May*, 1931.)

20. Describe switchgear for controlling and protecting an electric motor that drives a treble-ram pump. In what ways may such a motor be damaged electrically? (*2nd Class Exam.*, Nov., 1937.)

21. In connection with electricity, what is meant by insulation? What materials may be used for insulating in a large motor taking high-pressure current? How is the quality or state of the insulation tested? (*2nd Class Exam.*, May, 1939.)

22. Among the metals used in an electric motor are the following: copper, aluminium, cast-iron, mild steel, nickel steel, brass. Name parts that are made of one of these metals or that may contain one or more of them. (*2nd Class Exam.*, May, 1934.)

23. Describe briefly, using simple diagrams, the three chief types of d.c. motor, and state a purpose for which each type is peculiarly suitable. How is the direction of turning of each type reversed? (*1st Class Exam.*, Nov., 1931.)

24. In connection with electrical plant, describe an exciter and state for what purpose an exciter is used. (*2nd Class Exam*, May, 1937.)

CHAPTER VIII

ALTERNATING CURRENT PLANT

OSCILLOGRAPH records of the variation of the E.M.F. induced in a loop which is attached to an external circuit, as in Fig. 60, by means of slip rings, show that the variation is periodic, being zero when the conductors are passing through the neutral zone and having positive and negative maxima when the lines of force are cut with maximum velocity.

Root-mean-square (R.M.S.) Value of Alternating Current. Let OP in Fig 89 be a radius rotating in anti-clockwise direction with uniform angular speed a and let the time t be reckoned from the instant at which the point P occupies the position A. For any position of the point P the angle $POA = at$. Now let MP and NP be perpendiculars from P to the lines BB' and AA' respectively, then at any instant -

$$OM = NP = OP \sin at, \text{ and } ON = OP \cos at.$$

If we consider the movement of P from A to B, it is easy to see that the average of the squared values of OM and ON must be the same, hence -

$$\begin{aligned}\text{Mean value of } OP^2 \sin^2 at &= \text{mean value of } OP^2 \cos^2 at.\\ &= \tfrac{1}{2} \text{ mean value of } (OP^2 \sin^2 at + OP^2 \cos^2 at)\\ &= \frac{OP^2}{2} (\sin^2 at + \cos^2 at)\\ &= \frac{OP^2}{2}\end{aligned}$$

$$\therefore \quad \text{R.M.S. value of } OP \sin at = \frac{OP}{\sqrt{2}} = \frac{\text{maximum value}}{\sqrt{2}}$$

$$= 0{\cdot}7071\ E_{max}.$$

Three-phase Currents. If, instead of having a single loop placed on the periphery of an armature, three conductors are placed in positions 120° apart and are connected to three slip rings, the sinusoidal curves of E.M.F. and induced currents will be displaced, as shown in Fig. 90, by an angle of 120° from each other. It is important to note the instantaneous value of either the E.M.F.'s or currents in a three-phase system, for that is the system of transmission generally used in mining

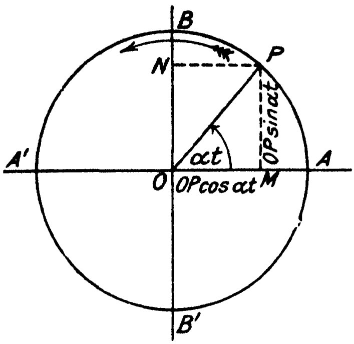


FIG. 89. R.M.S. VALUES OF E.M.F. AND C.

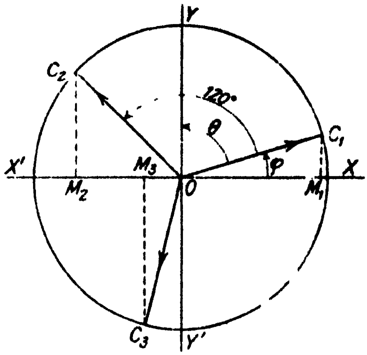


FIG. 90. THREE-PHASE CURRENTS.

work. The last figure represents three conductors 120° apart and connected at the point O, the ends C_1, C_2, and C_3 being connected to the slip-rings on the armature shaft. It is to be proved that the instantaneous value of the E.M.F. or current in the phase OC_1 is equal to the sum of the E.M.F.'s or currents in the other two phases OC_2 and OC_3, thus-

$$OM_1 = C\cos\phi = C\sin\theta \text{ (complementary angle)}$$

$$\begin{aligned} OM_2 &= C\cos(120^\circ - \phi) \\ &= C(\cos 120 \cos\phi + \sin 120^\circ \sin\phi) \\ &= C\cos 120^\circ \sin\theta + C\sin 120^\circ \cos\theta \end{aligned}$$

$$\begin{aligned} OM_3 &= C\cos(120^\circ + \phi) \\ &= C(\cos 120^\circ \cos\phi - \sin 120^\circ \sin\phi) \\ &= C\cos 120^\circ \sin\theta - C\sin 120^\circ \cos\theta \end{aligned}$$

Adding OM_2 to OM_3 we get $2\,C \cos 120^\circ \sin\theta = -2\,C\ \sin\theta$

$C \sin\theta = -OM_1$. This result may be interpreted as meaning that the sum of the instantaneous values of the E.M.F. or current in a three-phase system is *zero*, and that one of the cables acts as the return for the other two. Another important point relating to Gen. Reg. 124 (*c*) is that the point at which the cables or conductors are joined is at zero potential and consequently the system may be earthed at that point—the "neutral point" or "star point."

Star and Delta Connections. Fig. 91 shows alternative methods of connecting the windings of an alternator. That

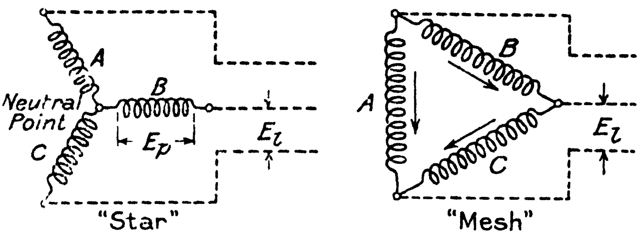


FIG. 91 PHASE CONNECTIONS

on the left is the "star" connection and that on the right the "delta" connection, or "mesh," as it is sometimes called. In considering the relations between *line* and *phase* voltages it is necessary to draw the vector diagram in Fig. 92. Taking the star connection first, we may find the line voltage E_l between the phases B and C, by subtracting the phase voltage of C from that of B. This is done by reversing the direction of OB and making $OB' = OC$, and afterwards drawing the resultant OR of the parallelogram $OCRB'$. Obviously, $OR =$

$OB' \cos 30^\circ + OC \cos 30^\circ = 2OC\,\frac{\sqrt{3}}{2} = \sqrt{3}\,OC$, therefore

$E_l = \sqrt{3}\,E_p$. The line and phase currents are equal. When the phases are mesh-connected, the lines are connected across the phases, and consequently the line voltage E_l equals the phase voltage E_p, but the currents are related in the same

way as the voltages in the star-connected system, that is $C_l = \sqrt{3}\, C_p$.

Inductive Circuits. If the current in a conductor is alternating the field surrounding it will also alternate, and consequently an E.M.F. will be induced in the conductor by the variations of the magnetic field due to the current itself. It is called the E.M.F. of self-induction. The unit of self-induction called the *henry* is defined as the induction of back-E.M.F. of 1 volt when the current is changing at the rate of 1 ampere

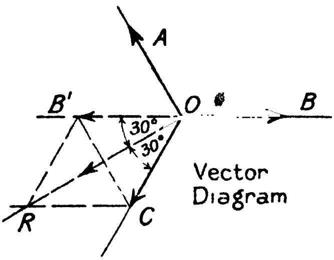


FIG. 92

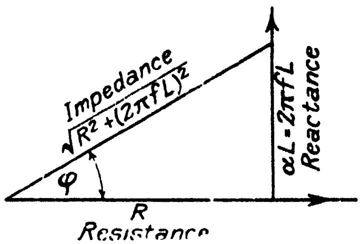


FIG. 93

per second. The effect of self-induction is to retard the flow of current through a conductor in which there is an alternating current, and consequently the applied E.M.F. has to overcome the ohmic resistance of the conductor and the *reactance* produced by self-induction L. The resistance R is in quadrature with the reactance aL, and as $a = 2\pi f$, where f is the frequency of the alternations, we have the effective resistance, called the *impedance*, given by $\sqrt{R^2 + (2\pi f L)^2}$. The current in an inductive circuit takes some time to rise to its maximum value after the application of E.M.F. to the circuit, and therefore the current lags behind the E.M.F. by an angle whose tangent is given by $\dfrac{2\pi f L}{R}$. Fig. 93 shows relations of R, aL, and $\sqrt{R^2 + a^2 L^2}$.

Example 39. An alternating P.D. having a maximum value of 100 volts and a frequency of 50 alternations per second is

applied to a circuit having a resistance of 10 ohms and a self-induction of 0·01 henry. Find the maximum current, the impedance, and the phase difference between the current and the applied P.D.

Solution.

$$C = \frac{E}{\sqrt{R^2 + (2\pi fL)^2}} = \frac{100}{\sqrt{10^2 + (2 \times 3{\cdot}14 \times 50 \times 0{\cdot}01)^2}}$$

$$= \frac{100}{\sqrt{100 + 3{\cdot}14^2}} = \frac{100}{10{\cdot}5} = 9{\cdot}52 \text{ amperes}$$

Impedance, $I = \sqrt{10^2 + 3{\cdot}14^2} = 10{\cdot}5$ ohms

Angle of lag, $\phi = \tan^{-1} \frac{3{\cdot}14}{10} = \tan^{-1} 0{\cdot}314 = 17^\circ\ 26'$

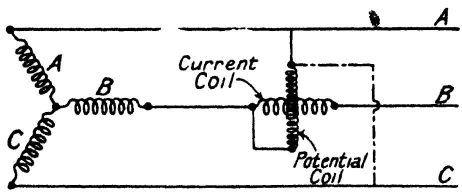


FIG. 94 WATTMETER CONNECTIONS

Power in Inductive Circuits. The power in a single-phase circuit is given by $W = EC \cos \phi$, where E and C are R.M.S. values of voltage and current and ϕ is the angle of lag. In a three-phase system the total power may be measured by putting a wattmeter in each phase and adding together the readings, or two wattmeters in phases B and C, with their potential coils connected to phase A, may be used to measure the power, the total power being the sum of the readings, but the same result may be obtained by connecting one wattmeter as in Fig. 94, so that its potential coil may be connected at will to phase A or phase C. In this way two distinct readings of power are obtained, and it is to be shown that the sum of such readings gives the total power in the circuit, but it is necessary to remember that we have already established the fact that the line voltage is 30° out of phase with the phase voltage. In addition to this, it must be noted that the current in the phase B lags behind the voltage in the

phase by an angle ϕ. The sum of the readings $= CE \cos (30^\circ + \phi) + CE \cos (30^\circ - \phi) = CE [\cos (30^\circ + \phi) + \cos (30^\circ - \phi)] = CE [\cos 30^\circ \cos \phi - \sin 30^\circ \sin \phi + \cos 30^\circ \cos \phi + \sin 30^\circ \sin \phi] = 2 CE \cos 30^\circ \cos \phi = 2 CE \frac{\sqrt{3}}{2} \cos \phi = \sqrt{3}\, CE \cos \phi$ watts.

The power in the circuit $= \dfrac{\sqrt{3}\, CE \cos \phi}{746}$ h.p.

Determination of Power Factor. In the preceding paragraph it was shown that the sum of the wattmeter readings $W_1 + W_2 = 2\, CE \cos 30^\circ \cos \phi$, and in a similar manner it may be shown that $W_1 - W_2 = 2\, CE \sin 30^\circ \sin \phi$, hence the power factor may be found from two wattmeter readings by combining these expressions, thus:—

$$W_1 - W_2 = 2\, CE \sin 30^\circ \sin \phi = 2\, CE . \tfrac{1}{2} \sin \phi = CE \sin \phi,$$

and $$\frac{W_1 - W_2}{W_1 + W_2} = \frac{CE \sin \phi}{\sqrt{3}\, CE \cos \phi} = \frac{1}{\sqrt{3}} \tan \phi,$$

and $$\tan \phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

It is important to note that the greater the value of ϕ the smaller is the value of the power factor, and that when $\cos \phi$ is 1 the current and voltage are in phase, in which case the product of volts and amperes gives true watts. When $\cos \phi$ has any other value than 1, the voltage and current are out of phase, and consequently true watts can only be obtained by multiplying apparent watts by $\cos \phi$, hence the power factor, $\cos \phi = \dfrac{\text{true watts}}{\text{apparent watts}} = \dfrac{\text{watts}}{\text{volt-amperes}}$. In practice a meter may be attached to the switchboard to enable the *power factor* to be determined, or it may be determined from readings of a wattmeter, a voltmeter and an ammeter.

Example 40. Calculate the power in a single-phase system if the R.M.S. voltage and current are 420 and 75 respectively, the power factor being 0·8.

Solution.

$$\text{Watts} = CE \cos \phi = 420 \times 75 \times 0{\cdot}8 = 25{,}200$$

$$\text{H.P.} = \frac{\text{Watts}}{746} = \frac{25{,}200}{746} = 33{\cdot}8$$

Example 41. The voltmeter and ammeter attached to a 3-phase circuit read 500 and 110 respectively, the power factor being 0·85. Calculate the input horse-power to the circuit.

Solution.

$$\text{H.P.} = \frac{\sqrt{3}\,CE\cos\phi}{746} = \frac{1{\cdot}73 \times 500 \times 110 \times 0{\cdot}85}{746}$$

$$= 108{\cdot}4$$

Example 42. Two wattmeter readings are obtained on a balanced three-phase circuit, one being 17,640 watts, the other 2178. Calculate the power factor of the circuit.

$$\tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \frac{1{\cdot}73\,(17640 - 2178)}{17640 + 2178} = \frac{1{\cdot}73 \times 15462}{19818}$$

$$= 1{\cdot}35, \text{ and } \phi = 53^\circ 28'$$

Referring now to a table of natural cosines, it is seen that $\cos 53^\circ\ 28'$ is 0·5953, which is the power factor.

The Effect of Capacity in Inductive Circuits. The effect of capacity in an inductive circuit is to reduce the total resistance of the circuit, and consequently to increase the efficiency with which the circuit is operated. In considering the effect of inductance we saw that impedance was expressed by $\sqrt{R^2 + (2\pi fL)^2}$, but since the combined effects of inductance and capacity may be expressed by $\sqrt{R^2 + \left(2\pi fL - \dfrac{1}{2\pi fK}\right)^2}$, where K is the capacity in microfarads in the circuit. Capacity is distributed throughout the whole of an electric circuit and it is sometimes introduced into an inductive circuit with the view of increasing the power factor. It is easy to see that when $2\pi fL = \dfrac{1}{2\pi fK}$, there can be neither lag nor lead, and, therefore, electrical resonance exists.

Example 43. Calculate the capacity of a condenser necessary to neutralize the effect of an inductance of 0·25 henry, if the periodicity of the current is 50 cycles per second.

Solution.

$$\text{Since } 2\pi fL = \frac{1}{2\pi fK}$$

$$K = \frac{1}{(2\pi f)^2 L} = \frac{1}{(2 \times 3{\cdot}14 \times 50)^2 \times 0{\cdot}25}$$

$$= 40{\cdot}7 \text{ microfarads.}$$

Alternators. An alternator may have but a single-phase winding, or it may have a two-phase winding, but for mining

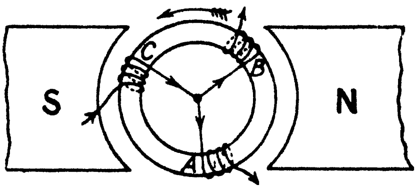


FIG. 95 SIMPLE ALTERNATOR

work it is usual to have a three-phase winding, thus constituting a *polyphase* alternator. Fig. 95 shows three armature coils connected at the neutral point in a star connection and the armature rotating in a magnetic field between the poles N and S of a two-pole alternator. The arrows show the direction of rotation of the armature and the direction in which the currents are passing in the armature coils. In the coil A, which is just beginning to cut the lines of force, the E.M.F. is increasing, while the E.M.F. in the coil B is diminishing and has the same direction as that in the coil A. The coil C is passing in front of the S pole, and consequently the E.M.F. is opposite in direction to the E.M.F.'s in the coils A and B. As the ring continues to rotate the E.M.F.'s induced in the armature conductors vary from positive maximum to negative maximum and vice versa in each revolution, and as the coils are spaced at angles of 120° on the armature the phase relationship between the E.M.F.'s will also be 120°

If the free ends of the coils are now connected to three insulated slip-rings mounted on the armature shaft the induced currents may then be transmitted for the supply of power and lighting units. Alternators may have multiple poles, and when an alternator has multiple poles, N and S poles arranged alternately, each conductor passes under a N and S pole alternately, and in doing so experiences the complete cycle on changes in the electromotive force induced in it. I such a machine the periodicity of the current will be equal to the number of revolutions of the armature (or field) per second, multiplied by the number of pairs of magnet poles, or periodicity $= f - \frac{Np}{60}$. The periodicity, or frequency, adopted in practice varies from 25 to 50, the higher figure being that most commonly used for power and lighting, but where power is the only consideration the frequency may approach the lower figure. Since the field in which the armature rotates is constant, it is necessary that the electromagnets should be excited by means of a direct current, and that is usually provided by a small D.C. dynamo which may be driven separately or mounted on an extension of the base plate and shaft of the alternator. Two main types of alternators are in general use. In one type the armature revolves and the field magnets are stationary, and in the other the field magnets rotate and the armature coils are disposed around the laminated shell of the stator. The arrangement of the stator of the former is precisely like that of a D.C. generator, but in the case of the latter the windings normally forming part of the armature are placed in the slots of a laminated shell. The rotor of the latter type consists of a wheel (usually of cast-iron), to the rim of which the poles are bolted. Each pole is provided with a field coil which is wound on a strong spool with heavy flanges Fig. 96 shows a colliery turbo alternator with exciter on the main shaft.

The E.M.F. of an Alternator. Let ϕ be the flux per pole and N the number of revolutions of the armature per minute, then the total number of lines cut by an inductor per second

(The General Electric Co Ltd

FIG 96 TURBO ALTERNATOR WITH EXCITER AND SWITCHBOARD

$= 2p\phi$, and the electromotive force $= \dfrac{2\phi Np}{60} \times 10^{-8}$ volts per inductor. If there are Z inductors in series, the average E.M.F. $= E_a = \dfrac{2\phi ZNp}{60 \times 10^8}$, but as the winding is necessarily distributed over the surface of the armature, some of the inductors must be more efficient than others, and consequently the foregoing must be multiplied by k, the "form factor," to obtain a nearer correct value of E_a. The value of the factor may be ascertained from an oscillograph curve, but if the curve is assumed to be sinusoidal, k is found by dividing the R.M.S. ordinate by the average ordinate

$$= \frac{1}{\sqrt{2}} \div \frac{2}{\pi} = 1{\cdot}11,$$

and the virtual voltage becomes—

$$E_v = \frac{2{\cdot}22\phi ZNp}{10^8 \times 60} = \frac{2{\cdot}22\phi Z_f}{10^8}$$

Example 44. A 10-pole alternator makes 1500 revolutions per minute. The armature is made up of 10 coils of 40 turns each connected in series. The flux per pole is 10^6 lines. Calculate the open circuit E.M.F., assuming a sinusoidal curve of potential.

Solution. Since there are 10 coils of 40 turns there must be twice that number of inductors

$$\therefore E_v = \frac{2{\cdot}22 \times 10^6 \times 10 \times 40 \times 2 \times 1500 \times 10}{10^8 \times 60 \times 2} = 2220 \text{ volts}$$

Relation of Speed to Voltage. The formula deduced in the preceding paragraph shows that the voltage (E_v) is directly proportional to speed provided all the other factors are constant, but as the speed is altered during an experiment the exciting current, and, therefore, the field flux, changes, so that in order that the exciting current may remain constant the resistance in the exciter circuit must be varied.

Synchronizing Alternators. The variations of load on a colliery power station are so great that it is generally desirable for reasons of efficiency to install more than one alternator. The load factor of an alternator should always be high to

enable it to work efficiently, and if the load should normally be, say, 1000 kW., but sometimes be nearer 500 kW., it would obviously be better to have two 500 kW. sets than one of greater capacity. When it is necessary to run two alternators to feed the same power circuit care must be taken to ensure that the voltages of the alternators are exactly alike. Several methods are available for *synchronizing* alternators. The Westinghouse Company make a synchroscope which consists of a voltmeter in conjunction with two small transformers. When the voltages are equal the moving pointer indicates the zero position, but if the voltages are not equal the moving pointer indicates whether the incoming alternator is moving too fast or too slow. An alternative method of determining when alternators are in synchronism is to connect a lamp between the *A* phase of one alternator and the *C* phase of the other, when the lamp will glow at synchronism, but if the lamp is connected across the *C* phases, it will remain dark at synchronism.

Alternator Tests. It is important that the reliability of the insulation of the stator and rotor of alternators should be proved by a severe test prior to installation. The tests commonly applied are: 1. A pressure equal to twice rated pressure plus 1000 volts is applied between stator windings of each phase and between any coil and earth for one minute. 2. The rotor winding is tested to earth for one minute at ten times the rated pressure, with a minimum of 1500 volts. 3. The machine is run for six hours at full load and the temperature should not rise more than 40° C. above that of the surrounding atmosphere.

Switchboard for A.C. Machines. An alternating-current generator switchboard comprises three sections, or panels, arranged across the switchboard in the order from right to left of generator panel, instrument panel, and feeder panel. Should there be two alternators in a power station there would be a separate panel for each, and there are usually just as many feeder panels as there are main branches or circuits, each section being appropriately labelled.

The equipment for the generator panel will be as follows—

1. One 3-pole bus-bar isolating switch interlocked with the main oil switch.

2. One 3-pole oil-break circuit breaker fitted with balanced current protection device.

3. Three overload and three time-limit fuses.

4. Six current transformers for balanced current protection.

5. One single-pole reverse power relay.

6. Three spring-controlled ammeters with current transformers.

7. One wattmeter, one voltmeter, and one earthing switch.

8. One exciter pedestal, fitted with main field ammeter and voltmeter, one single-pole field breaking switch and hand-wheel for operating exciter field rheostat.

The essential equipment of the instrument panel would be as follows—

1. One synchronizing voltmeter.

2. One bus-bar voltmeter, and one "incoming machine" voltmeter.

3. One synchronizing plug socket, with synchroscope and amps.

4. One three-phase power factor meter.

5. One three-phase potential transformer with high-tension and low-tension fuses and single-pole isolating links.

Each feeder panel would have the following equipment-

1 One 3-pole bus-bar isolating switch interlocked with main oil switch and provided with earthing jaws.

2. One 3-pole oil-break main circuit breaker.

3. One spring-controlled moving-iron ammeter

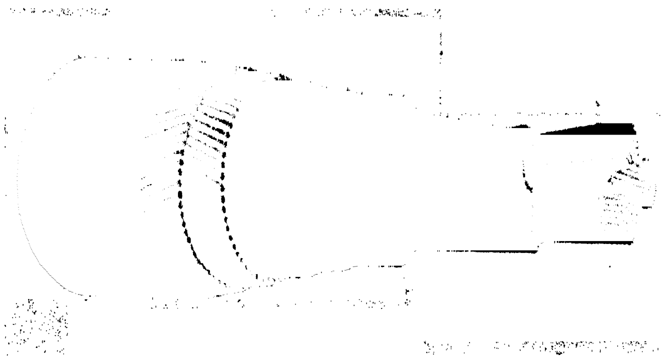
4. Time limit fuses and current transformers.

5. One 3-phase wattmeter.

As it is usual to have a rotary converter or motor-generator in the power house for the purpose of providing a supply of direct current, provision would have to be made for the requisite controls and instruments on a separate panel.

Shaft Cables. The alternating current generated on the surface is transmitted to the distribution panel at the bottom

of the shaft by means of a three-core cable such as that shown in Fig. 97. Having regard to the need for the cables being strong and capable of resisting the effect of the moisture or water in the shaft, shaft cables are double-wire armoured and are insulated with vulcanized bitumen, or impregnated paper, either of which serves the double purpose of preventing leakage of current and accession of moisture to the interior



(*W. T. Glover & Co., Ltd.*)

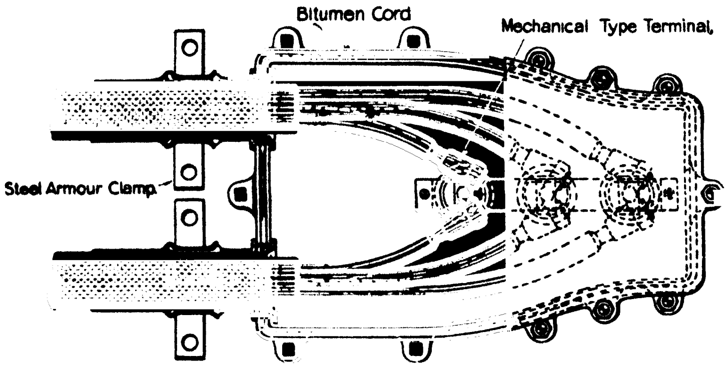
FIG. 97. "SOLBIT" THREE-CORE D.W.A. CABLE

of the cable. The figure shows a "Solbit" cable, consisting of three cores covered with rubber, each strand being completely filled with bitumen effectively to exclude moisture. The cores are laid on a cradle of bitumen compound, and are enclosed in bitumen. Two servings of braid and the double-wire armouring complete the cable, except for the outer covering of tarred jute. Paper-covered cables are metallically enclosed, the covering taking the form of a cylindrical, seamless sheath of lead put on by hydraulic pressure. The armouring of all cables working above the low-pressure limit of 250 volts must have an effective conductivity of 50 per cent of the largest conductor enclosed.

Fig. 98 shows in part section a joint box such as is used to connect adjoining length of shaft. The conductors are attached to thimbles in the box and the armouring to clamps

which are bonded across the box, and the interior is filled with bitumen to exclude moisture. The box is generally built up on a concrete or brick pillar situated in a shaft mouthing.

Earthing. Electricity Rule 125 (*a*) requires that "all metallic sheaths, coverings, handles, joint-boxes, switchgear frames . . ., unless efficiently protected by an earthed or insulating covering of fire-resisting material, and the frames



(*W. T. Glover & Co., Ltd.*)

FIG. 98. JUNCTION BOX FOR JOINING SHAFT CABLES

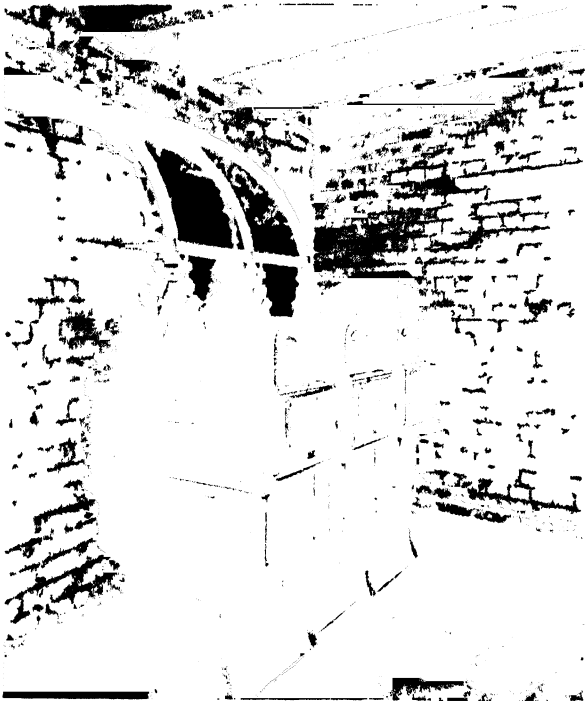
and bed-plates of generators, transformers, and motors (including portable motors) shall be earthed by connection to an earthing system at the surface of the mine."

An efficient earthing system consists of a ribbed cast-iron plate placed in a trench and surrounded by coke or coke breeze, the whole being maintained in the wet condition to ensure a reliable connection to earth. All armourings are bonded, and every other part of the system which might become live is connected to the earthing system on the surface by means of the bonded armouring. As an efficient earth conductor is compulsory and cables may not be armoured, the compulsory earth conductor is embodied in the cable, thus constituting a four-core conductor, and in the special case of coal-cutter trailing cables it might be necessary to include a pilot wire for earthing purposes.

Switchgear. As it is usually necessary that power should be transmitted to several points in a mine, some provision must be made for distributing the current to the several branches of the system, and that involves the installation of a distribution box or switchgear in a convenient position near to the shaft. Such a switchgear is provided with three bus-bars housed in a chamber of rectangular section, and the switchgear controlling the passage of current to the several branches is contained in suitable panels that are connected to the housing containing the bus-bars. The controlling switches are designed so that the circuit can be broken or made in air or oil, and it is usual to provide such switches with automatic overload and no-load releases so that the circuit may be broken automatically in the event of overload or a sudden or gradual failure of the voltage. Fig. 99 shows a group of three units placed in a room near to the bottom of a shaft. Each unit comprises an oil circuit breaker on a sliding carriage mounted on stout framework to which is bolted the bus-bar chamber, ammeter, instrument transformer chamber, and cable boxes. Connection is made from the circuit breaker to the bus-bars by a special wedge-shaped moving contact of the self-aligning pattern, which engages with a fixed embracing contact. Interlocks are provided so that it is impossible to inspect the circuit breaker unless the carriage is fully withdrawn. In each of the phases of some switchgear units there is a current transformer, and two of these are designed to operate the circuit breaker on overload and have time-limit fuses attached to them. The secondary current in the transformer of the remaining phase energizes a plunger which compresses a spring, but should the voltage fall the expansion of the spring is arranged to trip the circuit breaker. When a motor is started up there is an abnormal rush of current in the feeder circuit, and unless heavy metallic fuses of the ordinary type were used they would be burnt out at once, but if the *fuses* have a definite time lag embracing the period of high amperage the motor may be started up and the current allowed to fall to normal before the tripping

mechanism has had time to operate Time-limit fuses of the most efficient type are described in *Colliery Electrical Engineering*, by G M. Harvey

Road Cables. It is required by Rule 129 (*c*) that "Concentric cables, or two-core or multi-core cables protected by



(*General Electric Co Ltd*)

FIG. 99 DISTRIBUTION SWITCHGEAR AT THE BOTTOM OF A SHAFT

a metallic covering which shall contain all the conductors of the circuit, shall be used (i) where the pressure exceeds low pressure, (ii) where the roadway conveying the cables is also used for mechanical haulage, and (iii) where there may be risk of igniting gas coal-dust, or other inflammable material"

In the circumstances stated armoured cables are necessary. Such cables may, like D.C. cables, be laid in troughing or they may be suspended by canvas slings attached to roof supports. When power is transmitted over considerable distances it is usually found necessary to join the cable in sections by means of joint-boxes, and when the cables are laid in haulage roads the joint-boxes should be placed on brick or concrete pillars in recesses along the side of the road, and the cables should, if possible, be guarded by the roof supports where they enter the joint-boxes. Joint-boxes of cast-iron should embody the following features

1. The castings should be sound and of ample proportions to render the connectors readily accessible.

2. The mechanical connectors should be rigidly attached to insulators fixed in the box, and the maximum conductivity should be attainable without soldering.

3. Boxes should be provided with ample openings to admit of their being filled with sealing compound, and such openings should be provided with covers.

4. Substantial clamps should be provided for securing the armouring to the boxes, and a bond of tinned copper having a conductivity equal to that of the armouring should be rigidly attached to the armouring of the cables as they enter and leave the boxes.

Size of Cables for A.C. Transmission. We have seen that the resistance of a cable depends on the specific resistance of the material in the cable, the length and the area of the cable, and it has been shown that in accordance with Ohm's law there is a drop in pressure when a current is sent through a cable, but it must also be noted that the drop in transmission is influenced by variations of temperature, since the resistance varies with changes of temperature. The temperature effect is so small under ordinary conditions that it is ignored, and consequently we can combine the formulae, $R = \frac{\rho L}{A}$ and $R = \frac{E}{C}$ to obtain a formula by which to

calculate the drop in volts between two points on a D.C. cable, thus—

$$E = \frac{C\rho L}{A}$$

Assuming that the length of a two-core cable is 100 yd., equal to 200 yd. of a single core, and that the current density is 1000 amperes per sq. in., we find that the drop in volts—

$$E = 1000 \times 0{\cdot}66 \times 10^{-6} \times 200 \times 36 = 4{\cdot}8 \text{ volts.}$$

The volts drop on a three-phase circuit, including lead and return conductors, is 1·73 times the drop in one conductor, therefore the voltage drop in a three-core cable carrying alternating current is $\frac{\sqrt{3} \times 4{\cdot}8}{2} = 4{\cdot}16$ volts. This method of determining the voltage drop does not take into account the ratio of the impedance of the circuit to the ohmic resistance, and, therefore, the result must be regarded as a first approximation to the result obtained when due allowance is made for the inductance and capacity of the circuit.

Example 45. Calculate the sectional area of a two-core cable and a three-core cable to transmit 150 amperes to a motor 1000 yards from the generator with a voltage drop not exceeding 50 volts.

Solution.

Voltage drop per 100 yd. $\frac{50}{10} = 5$ volts

Current density $\frac{5 \times 1000}{4{\cdot}8} = 1042$ amp. per sq. in.

Sectional area of cable $\frac{150}{1042} = 0{\cdot}144$ sq. in.

For a three-core cable—

Current density $\frac{5 \times 1000}{4{\cdot}16} = 1202$ amp. per sq. in.

Sectional area of cable $\frac{150}{1202} = 0{\cdot}125$ sq. in.

Example 45 (*a*). Electric power at the rate of 100 kW. at 500 volts is fed into a transmission line 1000 yd. long consisting of copper wire 0·57 in. diameter, whose resistance is 0·03 ohm per 100 yd. Calculate the drop in volts and the current in amperes—(*a*) if the current is direct, using two wires (*b*) if the current is three-phase, using three wires with unity power factor.

Solution.

(*a*) Current $= \dfrac{\text{watts}}{\text{volts}} = \dfrac{100 \times 1000}{500} = 200$ amp

$$\text{Drop in volts} = \frac{200 \times 0{\cdot}03 \times 1000 \times 2}{100} = 120 \text{ volts}$$

(*b*) Current $= \dfrac{\text{watts}}{\sqrt{3}E} = \dfrac{100 \times 1000}{1{\cdot}73 \times 500} = 115$ amp

$$\text{Drop in volts} = \frac{\sqrt{3} \times 120}{2} = 104 \text{ volts}$$

Transformers. A transformer is a device in which the inductive action of one circuit upon another is used to step-up or step-down the voltage of the primary current to that of the secondary. In its simplest form the static transformer used in conjunction with A.C. machinery consists of two circuits wound around an iron core, one circuit, the primary, being connected to the source of supply, whereas the other, the secondary, is attached to the machinery or other device supplied with the transformed current. Fig. 100 is a diagrammatic representation of a simple single-phase transformer having N_1 turns of wire on the primary side and N_2 turns on the secondary side. The alternating current in the primary circuit produces fluctuating flux in the iron core, and since the latter is linked with the secondary winding an alternating current is induced in the secondary winding, the E.M.F. in the latter being proportional to the number of turns of wire contained in it.

$$\frac{\text{E.M.F. in secondary}}{\text{E.M.F. in primary}} = \frac{\text{Number of turns in secondary}}{\text{Number of turns in secondary}}$$

$$\text{thus} \quad \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

Since the power in the secondary circuit equals the power in the primary, less the loss by leakage and resistance, we may write down the equation of powers,

$$C_2E_2 = KC_1E_1$$

where k is the efficiency of the transformer.

Example 46. The primary winding of a transformer is supplied with 100 amperes at 2200 volts. Assuming that the efficiency of the transformer is 95 per cent, find the current in the secondary corresponding to a voltage of 440.

$$C_2E_2 = KC_1E_1, \text{ therefore } C_2 = \frac{KC_1E_1}{E_2} = \frac{95 \times 100}{100} \times \frac{2200}{440}$$

$$= 475 \text{ amperes}$$

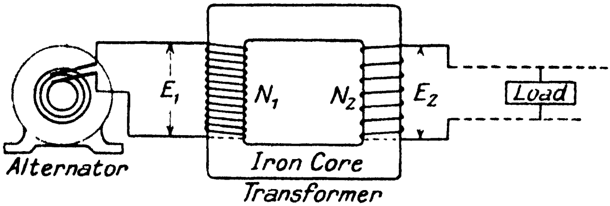


FIG. 100. SINGLE-PHASE TRANSFORMER

Three-phase transformers are commonly used for mining work and these are of the oil-immersed self-cooling core type. They are used in power transmission over great distances to step-up at one end of the line and to step-down at the other, and they admit of highly efficient transmission over long cables of small copper section. Step-down transformers are used to enable electric lighting to be carried into places where the voltage must of necessity be limited to the maximum of 25 volts.

Leakage Protection. It is desirable that provision should be made to guard against the danger arising from leakage faults to earth and leakage between phases in a three-phase system, and it is important that the protective devices should be automatic in action. Several methods are available for isolating the system in which a fault has developed, but the

method used in a particular case may depend on whether the system is mesh-connected or star-connected, and if the latter, whether the earthed neutral is accessible to the user of power. If the earthed neutral is accessible a current transformer may be attached to that with the earth wire in the primary circuit and a circuit breaker in the secondary circuit. Fig. 101 is a

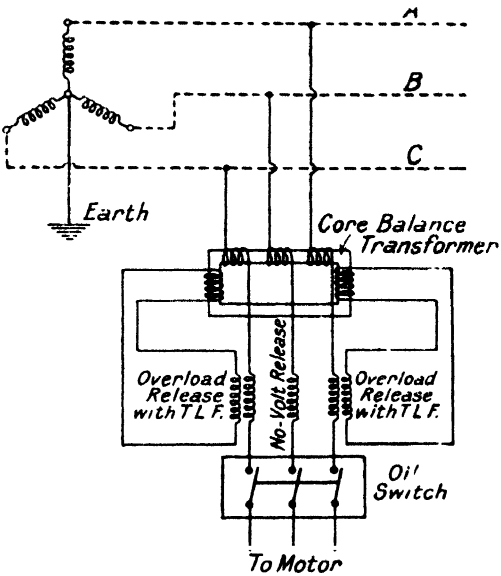


FIG. 101 LEAKAGE PROTECTION SYSTEM

diagrammatic representation of a core-balance leakage transformer attached to the mains.

In a three-phase system of transmission the algebraic sum of the currents at any instant is zero and, therefore, the neutral point of such a system is normally zero. But should a fault develop in one of the phases the balance is disturbed, and current would flow through the secondaries of the current transformer in the earth line of the first system and the core-balance transformer in the second case, and consequently the indicators attached to those secondary circuits would give

immediate warning of the occurrence of a fault in the mains and cause the tripping mechanism to operate on the switch of the faulty feeder.

Such devices give no indications of the early development of an incipient fault, and, therefore, it is necessary that periodic tests should be made to ascertain the condition of the insulation and the armouring and the conductivity of the cores of the cables. It is possible by means of such tests to

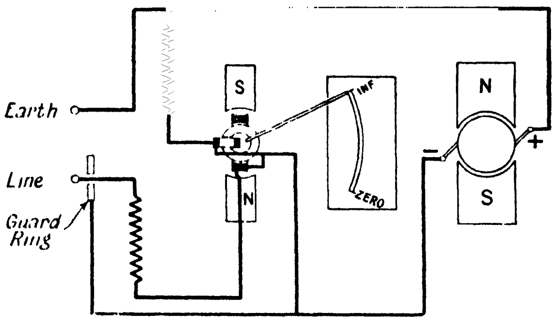


FIG. 102. "MEG" INSULATION TESTER

prevent serious breakdown of the plant by locating vulnerable points and making the necessary repairs.

Testing Instruments. Periodic tests of the insulation and the conductivity of the earthing of cables are necessary, and when faults occur it is necessary to locate them, therefore suitable instruments must be provided for making such tests as are necessary. These are an ohmmeter in conjunction with a generator for measuring insulation resistance, a low-reading ohmmeter in conjunction with a small accumulator for earth conductor tests, a Wheatstone testing set, including a galvanometer and dry battery for resistance measurements while repairs are being made, together with portable volt-meters and ammeters.

"Meg" Insulation Tester. Fig. 102 is a diagram of the connections of this handy instrument, which is made by Evershed & Vignoles, Ltd., Chiswick. It consists of an

ohmmeter and a generator having a permanent magnetic field, and when the generator is run at 100 revolutions per minute the instrument develops 500 volts, the scale of the ohmmeter being figured from zero to 100 megohms. The moving element of the ohmmeter consists of two coils turning on the same centre and having a pointer attached, and on examination of the figure it is seen that there are two paths for the current generated by the generator, one through the pressure coil, the other through the current coil. In using the instrument to test the insulation of a circuit, the circuit is connected to the line terminal of the set and the earth terminal is connected to earth. The generator is then rotated at 100 r.p.m., and if the insulation resistance is high enough, only the pressure coil is energized, and as that is wound for anti-clockwise rotation the pointer is caused to move against the pin at the reading of "infinity," but if the insulation resistance is low the current passes from the earth to the conductor connected to the line terminal, and through the current coil which is wound for clockwise rotation, thus causing the pointer to move across the scale until the moving element comes to rest with the pointer indicating the insulation resistance. A guard ring and shunt are provided to eliminate error from surface leakage.

Conductivity Test. This test is made by means of a 4-volt accumulator and a millivoltmeter. In testing a three-phase circuit for line conductivity and conductivity of the earthing system, the circuit is made dead by disconnecting it from the supply. The three conductors are short-circuited at the inbye end and connected to the armouring, and at the outbye end the accumulator is connected across the armouring and one of the phases; the millivoltmeter being connected across that phase and one of the other two. Let E_1 be the drop in volts as read on the millivoltmeter. Now connect the instrument across the first-mentioned phase and the armouring and observe the voltage drop E_2.

$$\frac{E_1}{E_2} = \frac{\text{voltage drop on line}}{\text{voltage drop on earthing system}}$$

Should the ratio exceed 0·5, it becomes necessary to locate the fault, which is most likely to be a joint of unduly high resistance. Everett, Edgcumbe & Co., Ltd., make a compact testing set suitable for this purpose. It consists of a low-reading ohmmeter, a small accumulator, and two metal spikes with insulated handles. The spikes are placed one on either side of a joint and the ohmmeter gives a direct reading of the resistance of the joint, hence the faulty one can be traced.

Fault in Armouring. Should the armouring of a cable come into contact with either of the cores of the cable the fault may be located by means of a galvanometer connected successively at points on the armouring a few yards apart. When the direction of deflection of the needle is seen to be reversed it is known that the fault lies between the points at which opposite deflections were observed.

Alternating-current Motors. The great majority of A.C. motors used in mining are of the induction type; that is to say, they are in principle similar to a transformer except that the primary winding of the *stator* is separated from the secondary winding of the *rotor* by an air-gap. In the stationary part of the motor the field windings are disposed around the inner surface of a laminated shell in which a rotating field is produced by the variations of the current passing through the stator windings. Similar currents are induced in the rotor windings when the rotor is a wound one and in the short-circuited bars of the rotor when that is of the squirrel-cage type. The magnitude of the currents induced in the rotor of an induction motor depends on the resistance of the rotor, and the starting torque of such a machine depends on the resistance of the rotor. Whereas the resistance of a wound motor may be varied by the introduction of a starting resistance in the rotor circuit, the resistance of a squirrel-cage rotor is fixed. Since the resistance of the latter is low, not only is the starting torque low but the magnitude of the induced currents is high, and consequently such motors must be fitted with a starter which will limit the currents induced in the rotor to the carrying capacity of the rotor bars. In the case

of the wound rotor, the three phases of the winding are connected in star at one end and the other ends are connected to three slip-rings mounted on the rotor shaft. Brushes are placed in sliding contact with these slip-rings, and leads are taken to

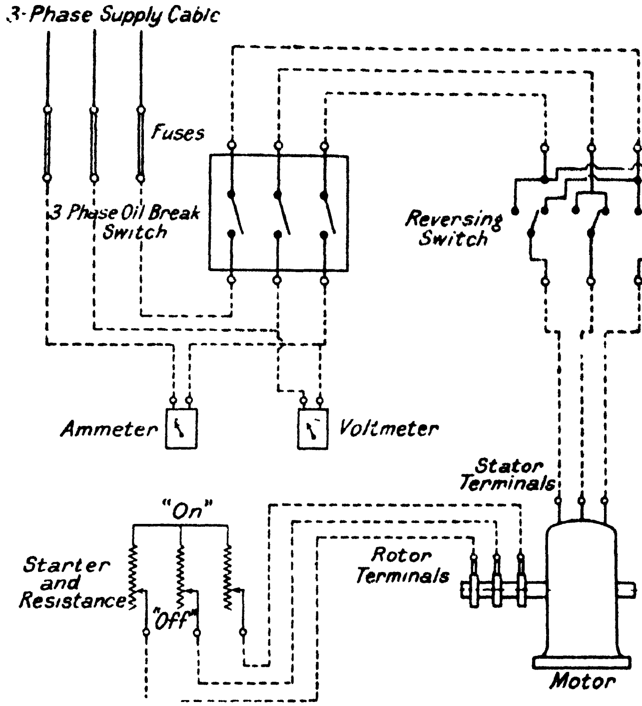


FIG. 103 WIRING OF ALTERNATING CURRENT MOTOR

three equal resistances which are diagrammatically represented in Fig. 103. It is seen that the stator windings are connected to the mains by a three-pole switch and fuses, and that the slip-rings are connected to three sets of resistance coils which are connected in star. If the movement of the switch arms is followed from " off " to " on " it will be seen that in the " on " position the slip-rings are short-circuited, just as the bars of the rotor of a squirrel-cage motor are short-circuited.

The resistance usually consists of wire or strips of high-resistance alloy, but when the motors are of large size, and have to be operated intermittently, liquid controls are used. The reversal of the direction of motion of an induction motor is effected by means of a reversing switch in the stator circuit.

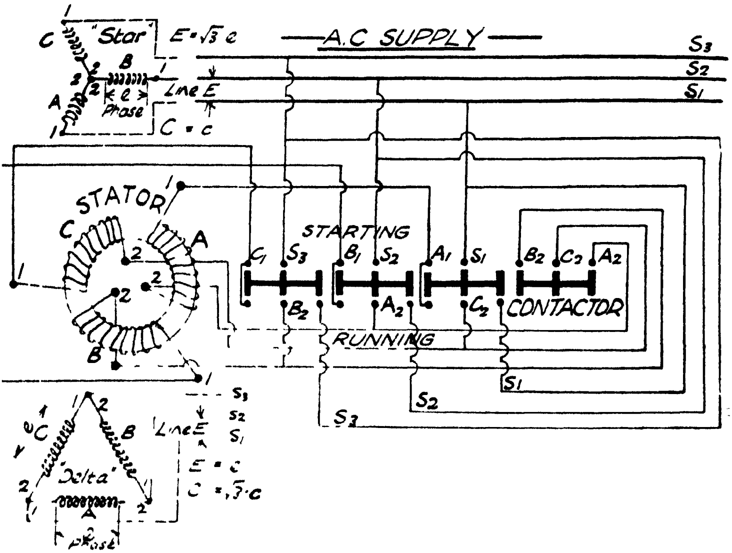


FIG. 104. CONNECTIONS FOR STAR-DELTA STARTER WITH KEY DIAGRAMS

The figure also shows the position of a reversing switch and the connections to the other parts of a three-phase motor equipment.

Methods of Starting Squirrel-cage Motors. There are three methods in general use for starting squirrel-cage motors, viz., by switching the motor direct on to the mains, by switching on to the mains through the medium of a star-delta switch, and by using an auto-transformer starter. The first method is that generally used in starting coal-cutters supplied with three-phase alternating current from a large supply, and the method is always satisfactory, since due allowance has been made for the large initial surge of current in designing the switchgear.

Star-delta Switch. When, for example, a coal-cutter has to be switched on to a small a.c. power supply, and it is desired to keep down the initial surge of current, a star-delta switch is placed in the supply circuit to the stator. The switch is wired so that the windings are star-connected at the start, thus providing that the impressed phase voltage is $\frac{1}{\sqrt{3}}$ of the applied line voltage, and the phase current equals the line current. When the motor has attained full speed, the switch

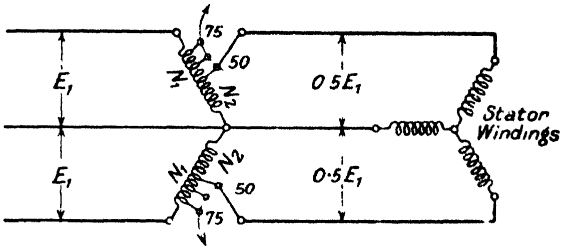


FIG. 105 AUTO TRANSFORMER STARTER

is moved over into the delta position, in which the phase voltage equals the line voltage and the phase current is $\frac{1}{\sqrt{3}}$ of the line current. The starting current is one-third of the short-circuit current, or five-thirds of the full-load current, and the starting torque is about one-third of the full-load torque; hence such a switch is only suitable for starting motors requiring to exert a comparatively small fraction of the full-load torque at the start. Fig. 104 is a diagrammatic representation of the connections in a star-delta switch. The contactor is moved upwards to make the *star* starting connections, and then it is moved downwards into the *delta* running position.

Auto-transformer Starter. Referring to Fig. 105, it will be seen that the stator windings of a squirrel-cage motor are connected by tappings to the windings of an auto-transformer, so that the phase voltage applied to the stator is a variable

fraction of the phase voltage of the supply according to the number of turns of the transformer windings tapped by the switch. The starting switch has as many contacts as there are tappings, and the number of these depends on the necessity for having a gradual increase in the voltage applied to the motor. Such starters are constructed on the principle of the transformer, but in this case a single winding only is necessary, for if N_1 be the number of turns of wire in the winding and E_1 be the voltage applied to it, the voltage obtained by tapping at N_2 turns from one end of the winding will be equal to $\frac{N_2}{N_1} \times E_1$. In practice auto-transformer starters are designed so that the voltage applied to the motor may be varied from 0·5 to the full voltage of supply, and since the starting torque may be more than half of the full-load torque this form of starter is capable of more general use than the star-delta starter. It is widely used in connection with three-throw and turbine pumps.

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EXERCISE QUESTIONS

1. What are the differences between a direct current and an alternating one? What is meant by a three-phase electric circuit? (*2nd Class Exam.*, Nov., 1924.)

2. State what is meant by the words in italics in the following description of a switch:—The switch is of the 3-phase *oil break, loose handle* type with *automatic overload releases* and *time limit fuses* in 2 phases and a *low-volt (or no-volt) release* in the third phase. (*2nd Class Exam.*, Nov. 1927.)

3. Describe a motor suitable for use with three-phase, 440 volt 50 cycle current to develop about 10 b.h.p. and to start against full load torque. Enumerate the conductors that would be connected to the motor, stating the part to which each would be connected and the function of each conductor.

(*2nd Class Exam.*, Nov. 1931.)

4. Explain the action of a three phase electric motor. What are the differences between a wound rotor and a squirrel cage rotor? State the particular uses of each type.

(*2nd Class Exam.*, May 1932.)

5. Describe the switchgear that may be installed at or near the coal face to control and protect the motor of a coal cutting machine (say 30 h.p. three phase, 50 cycles, 440 volts) and to protect the men working at or near the plant.

(*2nd Class Exam.*, Nov. 1932.)

6. An electric cable supplies three phase 50 cycle 400 volt current for driving a coal cutting machine, a face conveyor and a gate end loader. Specify the apparatus you would install at the end of the main cable when the supply branches to the three motors. (*2nd Class Exam.*, May 1933.)

7. An electric three phase motor developing 12 b.h.p. takes 10.3 kW. to drive it. What is the efficiency? If the volts are 400 and the amperes 18.0, what is the power factor?

(*2nd Class Exam.*, Nov., 1933.)

8. Electric three phase power is delivered by a three core cable to an underground pump-house at high pressure to work a three throw pump using power at medium pressure and taking 40 h.p. Describe the electric plant and apparatus that you would expect to find in and near the pump house, stating the purpose of each item. (*2nd Class Exam.*, Nov., 1934.)

9. Describe a three phase induction motor with squirrel cage rotor, and state what cable connections there would be. If 50 cycle current is used, what is the nearest approximate motor speed to 900 r.p.m.? (*2nd Class Exam.*, May 1935.)

10. Give a description of a switchgear unit for controlling the

supply of current to the stator of a three-phase electric motor (say, for 60 b.h.p. at 440 volts) and for giving information as to the power taken by the motor. The switchgear is to be suitable for an underground situation where explosive gas might be present. (*2nd Class Exam.*, Nov., 1935.)

11. What is a star-delta starter? Give a diagram of connections of the starter and the machine it controls, showing both the starting and the running connections. (*2nd Class Exam.*, May, 1936.)

12. In a three-phase electric circuit how are current and pressure (or voltage) measured or ascertained? A motor, when supplied with three-phase, 400-volt power, develops 30 h.p. at an efficiency of 90 per cent and a power factor of 0·8. What is the current in amperes? (*2nd Class Exam.*, Nov., 1936.)

13. What is meant when an electrical system is said to work at "50 cycles"? How many field poles should an alternator have to produce 50-cycle current at 375 r.p.m.? (*2nd Class Exam.*, May, 1937.)

14. Describe the construction and explain the mode of working of a three-phase induction motor with wound rotor. What metal is chiefly used for carrying electric currents in motors? What metal is used, and in what form, for the stator and rotor cores of a motor? (*2nd Class Exam.*, May, 1938.)

15. Describe suitable methods of starting the following motors, all of the three-phase type:

(*a*) A 5-h.p. motor at 400 volts with a squirrel-cage rotor,

(*b*) A 30-h.p. motor at 400 volts with wound rotor, driving a fan,

(*c*) A 60 h p. motor at 3300 volts with wound rotor, driving a direct rope haulage (*2nd Class Exam.*, Nov., 1938.)

16. A three-phase transmission line has bare copper conductors 0·04 sq. in. sectional area and is one mile long. The resistance of copper wire 0·04 sq. in is 0·6 ohm per 1000 yards. Electric power is fed to the line at the rate of 1000 kW. at 3000 volts, and the power factor is 0·8 What kilowatts are delivered by the transmission line? (*1st Class Exam.*, Nov., 1931.)

17. In connection with electric power, what is meant by the term "power factor"? What may be the causes of a low power factor? If a three-core cable were carrying its maximum current of 300 amp at 0·6 power factor and 3300 volts between phases, what extra power would be delivered if the power factor were raised to 0·8? (*1st Class Exam.*, May, 1932.)

18. Describe a synchronous induction motor, say, for use with three-phase, 2000-volt, 50-cycle current. If the motor is taking 100 kilowatts whilst the rest of the load on the system is 120 kVA

at 0·8 lagging power factor, what must be the power factor of the motor to make the general power factor unity?

(*1st Class Exam.*, Nov., 1932.)

19. A three-phase motor works at 240 b.h.p. when supplied with electric current at 3000 volts between phases. Its efficiency is 85 per cent and the power factor 0·75. Taking the pressure at the generator terminals as 3300 volts, what is the output of the generator in kilowatts to supply the motor?

(*1st Class Exam.*, May, 1933.)

CHAPTER IX

COMPRESSED-AIR PLANT

COMPRESSED air is extensively used for transmitting power in coal mines. It is not an efficient system of transmitting power, but it is believed to be safer to use than electricity, and for operations like rock-drilling it is eminently suitable. Vacuum plant is now used at several collieries in this country for the conveyance of coal from the coal face to a loading point at the end of the main haulage road.

Air is an elastic body which is capable of being compressed to considerable pressures, as for use in driving locomotives, and it may be expanded by means of an air-pump, when it is to be used in dust or coal extractors.

Equation of a Perfect Gas. The law of Boyle, connecting the volume and pressure of a certain mass of gas at constant temperature, is usually signified by—

$$p_1 v_a = pv, \text{ and thus } v_a = \frac{pv}{p_1} \quad . \quad . \quad . \quad . \quad (1)$$

The law of Charles, connecting the volume and absolute temperature of a certain mass of gas at constant pressure, is expressed symbolically thus—

$$\frac{v_1}{v_a} = \frac{T_1}{T}, \text{ hence } v_a = \frac{v_1 T}{T_1} \quad . \quad . \quad . \quad . \quad (2)$$

Combining (1) and (2) we get the general equation of a perfect gas

$$\frac{pv}{p_1} = \frac{v_1 T}{T_1}, \text{ therefore } \frac{pv}{T} = \frac{p_1 v_1}{T_1} = R \quad . \quad (3)$$

When air is at atmospheric pressure (14·7 lb. per sq. in.) and at the temperature of melting ice (32° F.), when the density

is 0·0807 lb. per cu. ft., the equation takes the particular form—

$$pv = \frac{144 \times 14{\cdot}7T}{(32 + 460)\,0{\cdot}0807}, \text{ or } pv = 53{\cdot}26T$$

Relations of Pressure, Volume, and Absolute Temperature. Certain relations of importance in air compression and utilization are deducible from the equation—

$$\frac{p_1v_1}{T_1} = \frac{p_2v_2}{T_2} = R$$

When the pressure is constant: $v_2 = \frac{v_1T_2}{T_1}$ and $T_2 = \frac{v_2T_1}{v_1}$

When the volume is constant: $p_2 = \frac{p_1T_2}{T_1}$ and $T_2 = \frac{T_1p_2}{p_1}$

When the temperature is constant: $p_2 = \frac{p_1v_1}{v_2}$ and $v_2 = \frac{p_1v_1}{p_2}$

When all the factors are variable: $p_2 = \frac{p_1v_1T_2}{v_2T_1}$; $v_2 = \frac{p_1v_1T_2}{p_2T_1}$

and $T_2 = \frac{p_2v_2T_1}{p_1v_1}$.

Isothermal Compression of Air. When air is compressed without the temperature of the mass of air being increased or decreased, the compression is said to be isothermal, and if a curve were to be drawn to show the relation of pressure to volume, such a curve would be an isothermal curve conforming to the law $pv = c$.

Adiabatic Compression of Air. If a certain mass of air is compressed in a cylinder which does not allow the heat of compression to escape, the temperature of the air increases at a definite rate, and the compression is said to be adiabatic. A curve of pressure and volume, called an adiabatic curve, conforms to the law $pv^{\gamma} = c$, where $\gamma = 1{\cdot}406$, hence the law of adiabatic compression is written $pv^{1{\cdot}406} = c$. Fig. 106 shows the curves of isothermal and adiabatic compression between the same limits of pressure, and it is seen that the

volume of compressed air under adiabatic conditions is greater than could be obtained with isothermal compression, but as the diagram is also a work-diagram it will be understood that the additional work which must be done during adiabatic compression is that represented by the area enclosed by the two curves. As the corresponding amount of energy would be lost as heat during transmission it is obvious that it is not

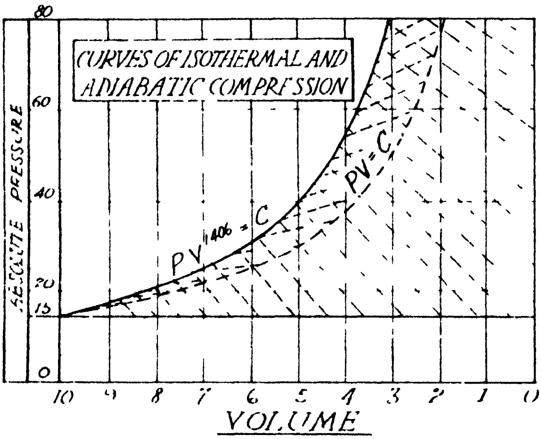


FIG. 106 AIR-COMPRESSION CURVES

desirable that air should be compressed adiabatically, but rather isothermally.

Heat and Work. The amount of work done in raising the temperature of a certain mass m of air from $t_1°$ to $t_2°$ F. can be stated in terms of Joule's equivalent as follows -

$$\text{Work done} = 778m\,(t_2 - t_1)\,s \text{ ft.-lb.}$$

where s is the specific heat of air, but if the amount of heat is ascertained from the heat carried away by the water flowing through the water-jacket of the compressors,

$$\text{Work done} = 778 \times \text{units of heat.}$$

Relations of Factors in Adiabatic Compression. By rearranging the factors in the equation $p_1v_1^\gamma = p_2v_2^\gamma$, we get $\dfrac{p_1}{p_2} = \left(\dfrac{v_2}{v_1}\right)^\gamma$,

and by re-arranging the factors in the equation $\frac{p_1v_1}{T_1} = \frac{p_2v_2}{T_2}$, we get $\frac{p_1}{p_2} = \frac{v_2T_1}{v_1T_2}$, and by substitution $\frac{v_2T_1}{v_1T_2} = \left(\frac{v_2}{v_1}\right)^\gamma$, hence $\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma - 1}$. We therefore have three useful formulae, viz.,

$$(1)\ \frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^{1.406}$$

$$(2)\ \frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\gamma - 1} = \left(\frac{v_2}{v_1}\right)^{0.406}$$

$$(3)\ \frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\gamma - 1}{\gamma}} = \left(\frac{p_1}{p_2}\right)^{0.29}$$

Since the action of compression is reversible, the formulae apply equally to adiabatic expansion, and the last may be used to explain the freezing of moisture in the ports of an air-engine.

Compressed-air Calculations. The student should familiarize himself with these calculations because of their intrinsic importance and the opportunity they offer for practice in the use of logarithms, especially in dealing with exponentials.

Example 47. Air is enclosed in a cylinder 4 ft. long and 2 ft. in diameter at a pressure of 15 lb per sq in. absolute. If the volume is slowly diminished to three-fourths of the volume of the cylinder, what will the pressure be (*a*) in pounds per square inch absolute, (*b*) in pounds per square inch by gauge?

Solution. The assumption that the compression takes place slowly admits of the application of Boyle's law to the change of pressure and volume, thus –

(*a*) $p_1v_1 = p_2v_2$, and $p_2 = \frac{p_1v_1}{v_2} = \frac{15 \times 4}{3} = 20$ lb. per sq. in. absolute.

(*b*) Since absolute pressure
= gauge pressure + atmospheric pressure

Gauge pressure
= absolute pressure – atmospheric pressure
= 20 – 15
= 5 lb. per sq. in.

The volume of the cylinder might have been calculated, but since its form is quite regular that is unnecessary.

Example 48. A compressor has compounded air cylinders 29 in. and 18 in. bore (inside diameter) by 42 in. stroke and runs at 110 r.p.m. What volume of air will be delivered to the receiver if the gauge pressure is 80 lb. per sq. in., assuming the volume to vary inversely as the pressure? What factor is ignored in this assumption? (Assume the atmospheric pressure to be 15 lb. per sq. in.)

Solution. This question was set at the Colliery Managers' Examination in the Province of Alberta, Canada, in June, 1924. Theoretically, the amount of compressed air delivered to the receiver after isothermal compression from atmospheric pressure is dependent on the volume swept by the piston of the low-pressure cylinder and the initial and final absolute pressures.

Volume swept by L.P. piston

$$= \frac{\frac{\pi}{4}d^2}{144} \times 2L \times \text{r.p.m}$$

$$= \frac{0{\cdot}7845 \times 29^2 \times 2 \times 42 \times 110}{144 \times 12}$$

$$= 3533 \text{ cu. ft.}$$

Assuming the compression to conform to the law $p_1v_1 = p_2v_2$

we get $v_2 = \frac{p_1v_1}{p_2} = \frac{15 \times 3533}{80 + 15} = \frac{3 \times 3533}{19} = 558$ cu. ft. per min.

The factor ignored in the assumption is that the compression does not really follow the law of isothermal compression, which is expressed by $p_1v_1 = p_2v_2$; the index of v being in reality a figure between 1 and 1·406, according to the number of stages of compression and the effectiveness of the arrangements provided for cooling the air during the process of compression.

Example 49. Calculate the weight of 1 cu. ft. of air at an elevation of 4000 ft., the pressure being 12·88 lb. per sq. in., and the temperature 60° F.

Solution. In Equation 3, p is the pressure in lb. per sq. ft., v is the volume of 1 lb. of air at the pressure p and temperature T,

therefore it follows that the weight of 1 cu. ft. of air under the specified conditions is given by the formula—

$$w = \frac{1}{v} = \frac{p}{53\cdot267}$$

$$= \frac{12\cdot88 \times 144}{53\cdot26\,(460 + 60)}$$

$$0\cdot06067 \text{ lb}$$

Example 50. Air at a pressure of 25 lb per sq in by gauge, and a temperature of 60° F, is compressed from a volume of 5 cu ft. to 2 cu ft, and at the same time is heated to 150° F. What will the pressure be under the altered conditions?

Solution. In the discussion leading to the statement of the characteristic of air it was shown that $\frac{p_1v_1}{T_1} = \frac{p_2v_2}{T_2} = R$, therefore,

$$\frac{(25 + 15) \times 5}{460 + 60} = \frac{p_2 \times 2}{460 + 150}, \text{ and } p_2$$

$$= \frac{40 \times 5 \times 610}{2 \times 520} = 117\cdot3 \text{ lb per sq in}$$

absolute, or 102·3 lb per sq in by gauge

Example 51. The water-jacket of an air compressor is maintained at a uniform temperature of 100 F, and 10 lb of water are passed per minute through the jacket. If the initial temperature of the water is 40 F, find the mechanical equivalent of the heat transmitted to the water

Solution. Heat given to the water

$$W(T_2 - T_1) = 10\,(100 - 40)$$

$$600 \text{ British Thermal Units}$$

Mechanical equivalent U

$$= JH = 778 \times 600$$

$$= 466{,}800 \text{ ft-lb}$$

Example 52. If 10 cu ft of air at a pressure of 15 lb. per sq in were compressed adiabatically to a pressure of 90 lb per sq in, what would be the volume of the compressed air?

Solution. $\frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^{1\cdot406}$; therefore $\frac{15}{90} = \frac{v_2^{1\cdot406}}{10^{1\cdot406}}$, and $v_2^{1\cdot406}$

$$= \frac{15 \times 10^{1\cdot406}}{90} = \frac{10^{1\cdot406}}{6}$$

Using logarithms—

$$1{\cdot}406 \log v_2 = 1{\cdot}406 \log 10 - \log 6$$

$$\log v_2 = \frac{1{\cdot}406 \log 10 - \log 6}{1{\cdot}406}$$

$$= \frac{1{\cdot}406 \times 1 - 0{\cdot}7782}{1{\cdot}406}$$

$$= 0{\cdot}4465$$

$$\therefore v_2 = 2{\cdot}8 \text{ cu. ft.}$$

Example 53. A certain volume of air at a temperature of 80° F. is allowed to expand adiabatically to twice its initial volume. What is the temperature of the expanded air?

Solution. $\dfrac{T_1}{T_2} = \left(\dfrac{v_2}{v_1}\right)^{0.406}$; therefore $T_2 = T_1\left(\dfrac{v_1}{v_2}\right)^{0.406}$

Using logarithms $\log T_2$

$$= \log T_1 + 0{\cdot}406 \log \frac{v_1}{v_2}$$

$$= \log (460 + 80) + 0{\cdot}406 \log \tfrac{1}{2}$$

$$= 2{\cdot}7324 + (\bar{1}{\cdot}8778)$$

$$= 2{\cdot}6102$$

$\therefore T_2 = 407{\cdot}6°$ absolute, or $- 52{\cdot}4°$ F.

Example 54. Air is taken into an air-compressor at a temperature of 50° F. and a pressure of 15 lb. per sq. in., and it is compressed adiabatically to a pressure of 60 lb. per sq. in. as registered by gauge. Find the temperature of the compressed air.

Solution. $\dfrac{T_1}{T_2} = \left(\dfrac{p_1}{p_2}\right)^{0.29}$, therefore $\dfrac{460 + 50}{T_2} = \left(\dfrac{15}{60 + 15}\right)^{0.29}$

$= (\tfrac{1}{5})^{0.29}$, and $T_2 = 510 \times 5^{0.29} = 813{\cdot}3°$ absolute or $353{\cdot}3°$ F.

Law of Actual Compression. In the ordinary case of air compression the law of the pressure-volume curve is similar to the laws governing isothermal and adiabatic compression, the essential difference being that the exponent of v in the formula $pv^n = C$ has a value between 1 and 1·406. The value of n depends mainly on the rate at which heat is abstracted from the air during the process of compression, and that is dependent on whether the compressor is double-acting or

single-acting, at least that generalization appears to be justifie by a study of diagrams taken from compressors working under ordinary conditions.

Fig. 107 was taken from the L.P. cylinder of a Walker compressor 20 in. diameter, and stroke 18 in., running at 180 r.p.m.

The compressor was running at full load and had water-jacketed cylinders, compression taking place on both strokes.

When v_1 was 8, p_1 was 19·2, and when v_2 was 5, p_2 was 33·2, and

$$n = \log\frac{p_1}{p_2} \div \log\frac{v_2}{v_1} = \frac{\log 0{\cdot}579}{\log 0{\cdot}626}$$

$$= \frac{\bar{1}{\cdot}7627}{\bar{1}{\cdot}7966} = \frac{-0{\cdot}2373}{-0{\cdot}2034} = 1{\cdot}17$$

The value of n as deduced from the diagram taken from the H.P. cylinder was found to be 1·21, therefore we may say that the value of n is not likely to exceed the figure given by Unwin, provided adequate provision is made for the rapid abstraction of the heat of compression from the air during the process of compression. It should, of course, be observed that while a low value of n denotes effective cooling systems, it may also indicate leakage of air from the pressure side of the piston to the suction side or to the atmosphere in the case of single-acting compressors.

Effect of Clearance Space on Compression. There must of necessity be some space provided between the piston at the extremities of its motion and the cylinder covers, and there must also be some space between the cylinder swept by the piston and the valves. Every part of the space within the cylinder not swept out by the piston is referred to as the *clearance space*.

The air in the clearance space has to be compressed at each stroke of the piston, but as there is little or no heat lost during the expansion of the air as the suction stroke is made, the the effect of the clearance space is to diminish the amount of air delivered to the receiver and consequently it is necessary

to provide a larger compressor for a given output than would be required in the case in which the clearance space was less. Fig. 107 shows that the fall of pressure to the atmospheric line is delayed because of the higher pressure of the air in the

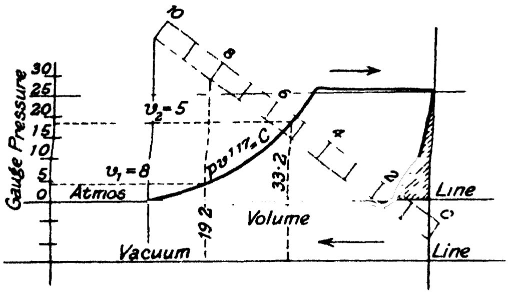


FIG. 107. COMPRESSION CURVE FROM WALKER COMPRESSOR

clearance space, but the diagram also shows that by the time the end of the stroke is reached the cylinder is full of air at atmospheric pressure.

Compression Efficiency. The ratio of the theoretical horse-power required to compress a certain volume of air between

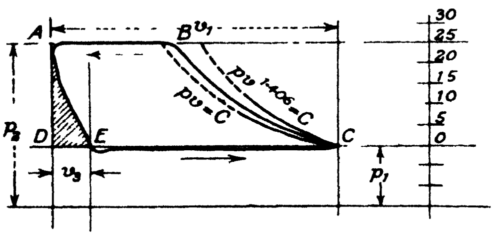


FIG. 108. INDICATOR DIAGRAM

defined limits of pressure to that actually required is an expression of the efficiency of compression, and the efficiency of compression depends upon the design and effectiveness of the water-jacket or other cooling devices, and, as we shall see, it is principally to increase the compression efficiency that multi-stage compression is employed. The simplest method of determining compression efficiency is to plot on the indicator

diagram the isothermal curve, starting at the beginning of the stroke and finishing on the terminal pressure line as in Fig. 108. The ratio of the area of the isothermal diagram to the area of the diagram drawn by the indicator gives the compression efficiency. The areas can be measured in a few moments by a planimeter. The area under the isothermal curve in Fig. 108 was found to be 250 units, and the area of the indicator diagram measured 245 units; therefore the efficiency of compression was 98 per cent.

Overall Efficiency. The overall efficiency is expressed by the ratio of the isothermal horse-power based on the delivered air to the brake horse-power at the shaft of the compressor The determination of the overall efficiency involves the calculation of the theoretical isothermal horse-power, the calculation being based upon the volume of free air delivered, and the ascertainment of the brake horse-power of the engine or motor which drives the compressor.

Example 55. An air compressor compresses and delivers 300 cu. ft of free air per min. The inlet pressure is 15 lb per sq in absolute, and the terminal pressure 90 lb per sq in absolute The brake horse power of the motor driving the compressor is 62 Required the overall mechanical efficiency of the compressor.

Solution. Isothermal horse-power

$$= 331 \cdot 2\, p_1 v_1 \log \frac{p_2}{p_1} \div 33{,}000$$

$$= 331 \cdot 2 \times 15 \times 300 \log \frac{90}{15} \div 33{,}000$$

$$= 42 \cdot 3$$

Overall efficiency

$$= \frac{42 \cdot 3 \times 100}{62} = 68 \cdot 2 \text{ per cent}$$

Broom and Wade's Single-stage Compressor. Fig. 109 shows the principal features of this compressor, and it will be sen that the suction valve, which is of the *poppet* type, is operated mechanically, the delivery valve being of the *plate* type The

compressor is used to compress air up to 120 lb. per sq. in., and the cylinders are designed so that the cylinder heads as well as the cylinder walls and valve pockets are available for water-cooling. Case-hardened parts are, where possible, used in the construction of the compressor, otherwise high-carbon

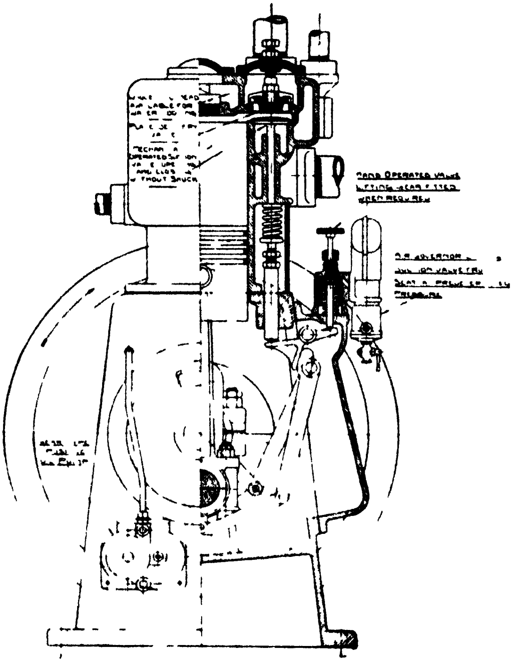


FIG. 109 BROOM AND WADE'S SINGLE STAGE COMPRESSOR

steel is used, and forced lubrication is provided for all bearings, crank pins and gudgeon pins. Owing to the use of mechanically operated suction valves, coupled with small cylinder clearance, the volumetric efficiency of the compressor is high, and since a number of small cylinders is used in preference to a single cylinder of the same capacity, the effective cooling surface is increased. The pistons are ribbed to enable them to be maintained, by conductivity, at practically the same

temperature as the walls of the cylinders, thus increasing the cooling effect by about 40 per cent.

Another important feature of the compressor is the governor by which the suction valves are lifted from their seats when a predetermined pressure is reached in the receiver. By this method of governing, when the machine is running on light load, the air is simply drawn in and exhausted from the cylinders at atmospheric pressure. The compressor is fitted with a fly-wheel so that the varying effort of the piston may be converted to an equalized effort in the driving mechanism. It need not be emphasized that when the compressor is driven by a directly connected steam-engine the greatest effort of the engine is made at the beginning of the stroke when the load is least. At the end of the stroke the conditions are reversed, hence the need for a balancing device

Action of Two-stage Compressors. Two-stage compression may be effected in one cylinder when the piston is of the differential form embodied in the Sentinel compressor, or it may be done in two separate cylinders of the double-acting type. Whatever may be the particular form of a two-stage compressor, its general arrangement and action may be studied in relation to the schematic diagram shown in Fig. 110.

Air at atmospheric pressure, called *free air*, enters the system at *A* and passing through the inlet valves at *B* enters the low-pressure cylinder. This takes place as the piston moves towards the right, and as air under the first stage of compression is forced from the L.P. cylinder through the valves *C* into the intercooler, so also is air drawn into the H.P. cylinder through the valve *D* to undergo the second stage of compression. It will be observed that while this has been taking place compressed air is forced through the valve *H* into the receiver. As the pistons move towards the left, air is drawn in the L.P. cylinder through the valve *F* and into the H.P. cylinder through the valve *E*. Simultaneously, partially compressed air is forced through the valve *G* into the intercooler, and air which has been compressed to the final pressure is forced through the valve *J* into the receiver.

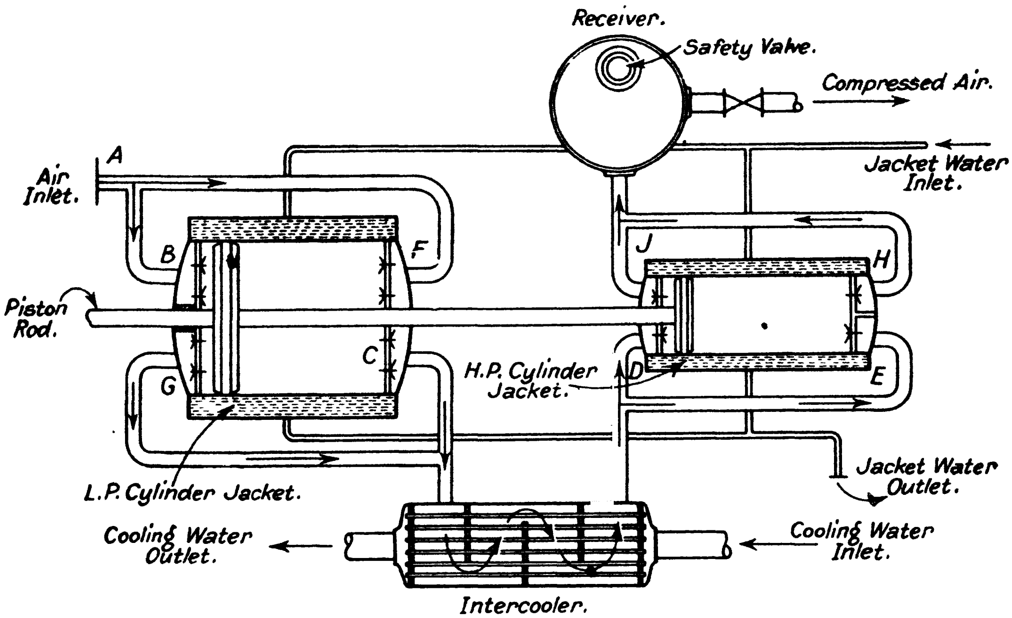


FIG. 110 ILLUSTRATING TWO-STAGE COMPRESSION

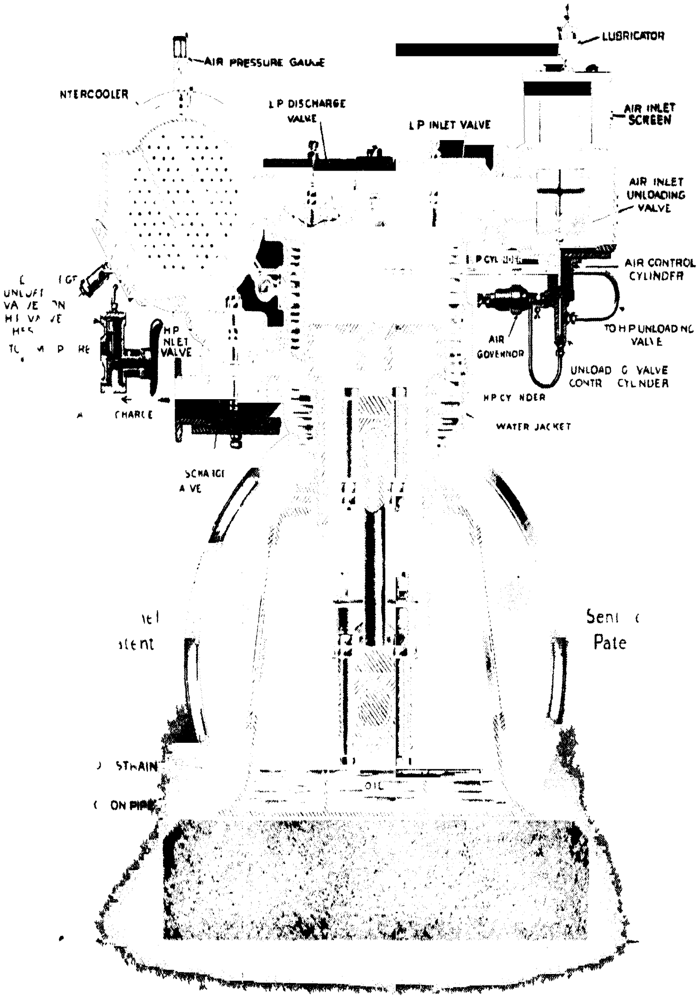


FIG. 111 SENTINEL AIR COMPRESSOR

It has been said that heat is produced during compression and that air cylinders are surrounded by water-jackets through which water is kept in constant circulation, but as water-jacketing alone does not reduce the temperature of the compressed air sufficiently the air is subject to further cooling as it passes from the L.P cylinder to the H.P cylinder. The device in which this further cooling takes place is called an intercooler, and on referring to Fig. 110 it will be seen that as the compressed air leaves the intercooler it is subjected to the maximum cooling effect by indirect contact with the cooling water as it enters the intercooler. It is customary to provide the receiver with a safety valve to guard against the effect of an explosion arising from the ignition of vaporized lubricant. It can be proved that the best relation of the pressures is $p_2 = \sqrt{p_1 p_3}$.

FIG. 112 CROSS SECTION OF SENTINEL VALVE

Alley and McLellan's Two-stage Compressor. The Sentinel compressor is of the single-cylinder intercooling type, and Fig. 111 shows that the piston is of the trunk or differential pattern, actuated by a crank-shaft through the medium of a connecting rod.

The space above the piston head forms the low-pressure or gathering cylinder, and the annular space below the piston head is the high-pressure or discharging cylinder. During the downward stroke of the piston, air from the atmosphere is admitted to the low-pressure cylinder past the multiple-ported valve shown in Fig. 112. When the motion of the piston is

about to be reversed the inlet valve closes the inlet to the low-pressure cylinder, and when further upward motion of the piston has compressed the air the discharge valve is opened, allowing the discharge of air through the low-pressure discharge valve box to the intercooler.

While the piston has been moving upward, air is drawn from the intercooler past the H.P. inlet valve into the annular space, the cylinder, and the portion of the piston of smaller diameter than the piston head, and the next downward stroke further compresses the air in that cylinder until it is discharged at the working pressure past the H.P. discharge valve to the receiver ready for use. The cylinder and its cover are thoroughly water-jacketed, so that the air may be cooled during compression, and between the two stages of compression the air is cooled down to the inlet temperature.

Sentinel Valves. The valves fitted to the Sentinel compressor are of the disc type, and their construction will be understood from Fig. 112. The valve *A* is made of tough steel in the form of a grid, and it is guided in relation to its seat *B* by the small steel cups *C*, which work in the guard *D* and engage with the valve at *E*, the valve being returned to its seat by springs *F* held within the cups *C*. It is seen that the valve is closed by a spring and does not depend for its action on any quality of spring possessed by the valve itself. The valves are placed in the cylinder cover with the object of reducing to a minimum the clearance in the cylinder.

Action of the Governor. When the pressure of the air in the receiver reaches the limit fixed as the working pressure an adjustable governor acts instantaneously on a throttle valve fitted to the air inlet and a release on the discharge, thus stopping the flow of air into the gathering cylinder. Fig. 113 is a sectional representation of the governor. Air from the receiver is admitted to the underside of the small piston *A*. The throttle valve *B* is loaded by an adjustable spring *C*, so that when the pressure in the receiver reaches the working limit the small piston *A* rises in its cylinder and, slowly lifting the throttle *B*, cuts off the entry of air to the compressor. As

the throttle valve closes, air is admitted to the small valve, which unloads the second cylinder, and so the compressor runs without load until the pressure in the receiver again falls slightly lower than the working pressure, when the throttle valve opens to allow air to pass to the gathering cylinder. It is obvious that this method of governing a compressor makes

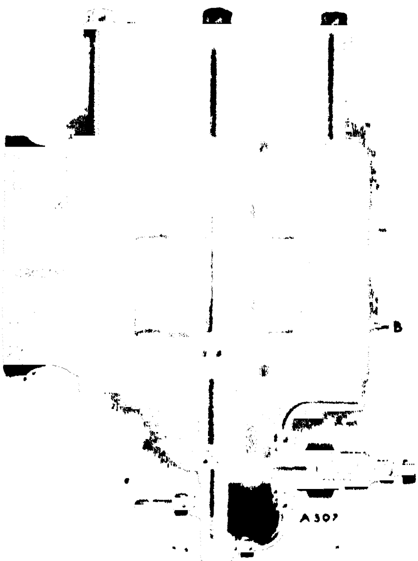


FIG. 113. SENTINEL AIR-GOVERNOR

for the greatest efficiency of working at all times, and when no air is being compressed the energy expended is practically only that required to overcome the inertia and friction of the moving parts of the compressor.

Intercooler and Aftercooler. An intercooler is a device through which air under compression is passed from one stage to the next higher stage with the object of reducing the temperature to such an extent that the whole operation of compression conforms closely to the law $pv = C$. In the smaller sizes of compressor it occupies the position shown in Fig. 111,

but intercoolers of large capacity are set up vertically, or mounted horizontally, on a separate foundation. Whatever the position or size may be it is usual to work intercoolers on the principle of counter-currents, that is, the air passes through the intercooler in the opposite direction to the cooling water. The basic idea regarding the construction of an intercooler is clearly shown in Fig. 111, where it is seen that a number of metal tubes are fitted to partitions in the cast body of the intercooler and that baffle-plates are formed in the body to give the air a circuitous path through the intercooler. The intercooler is cylindrical in form, and the water enters it at the end from which the air makes its exit. An aftercooler is essentially of the same form as the intercooler, except that it is connected to a compressing plant between the compressor itself and the receiver. The advantage of the aftercooler is that, like the intercooler, it enables water deposited from the air passing through it to be drawn off instead of being permitted to pass to the air-engines, in which it might be converted to ice during expansion of the air.

Receiver. It is always necessary to provide a reservoir for the storage of air as it comes from the compressor, and in view of the high pressures to which air is sometimes compressed it is customary to make receivers of mild steel with single-riveted and lapped circumferential joints and double-riveted lapped longitudinal joints. Every receiver should be fitted with a pressure gauge, a safety valve and a drain cock, and its volume should bear some proportion to the capacity of the compressor and the pressure of the power air.

Desirable Features in an Air Compressor. The conditions to be fulfilled in the design of an efficient reciprocating compressor, to which allusion has already been made, may be summarized as follows—

1. The inlet valve should admit of each cylinder of a compressor being completely filled through the stroke with air at the inlet pressure.

2. The air should pass through the inlet and discharge valves without appreciable rise in temperature.

3. Inlet valves should be perfectly air tight so that no portion of air being compressed may be discharged into the atmosphere.

4. Discharge valves should be so tight that no portion of the air which has been discharged into the receiver may be passed back into the cylinder to be compressed again.

5. As much as possible of the heat of compression should be abstracted from the air during compression.

6. The air should be cooled to inlet temperature by passage through intercoolers having adequate cooling surfaces and being supplied with sufficient cold water.

7. All parts should be easily accessible for examination and repair.

8. The lubricant chosen for the compressor should be capable of adequately lubricating the moving parts of the compressor which make contact with stationary parts and the lubricator should be designed to prevent admission to the cylinder or intercooler of excess of the lubricant.

Explosions in Air Compressors. It is known that explosions sometimes occur in some parts of an air-compressing plant, and sometimes there are *burnings* of carbonaceous deposit in some portion of the system. It may be that the combustion of carbonaceous deposit may be a preliminary to those explosions which take place. It appears to the writer that certain conditions must exist in order that an explosion may take place. In the first place there must be an adequate amount of some combustible substance which when ignited will cause a violent explosion, and in the second place there must be brought into contact with the combustible substance some source of heat which is capable of raising the temperature of the combustible substance to the ignition temperature. There are two possible kinds of carbonaceous, and therefore combustible, substance to be found in an air compressor, one arising from the vaporization of the oil used in lubricating the machine, the other being produced by the carbonization of the lurbicant. It is a well-known fact that combustible carbonaceous deposits are to be found in the air passages of

intercoolers, in the valve pockets, and in the discharge passages, and it is quite likely that these have gathered there on account of the cooling and the baffling influences to which the moving compressed air is subjected.

Turbo Compressor. The rotary form of air compressor was found to be such a satisfactory blower when used for supplying air to metallurgical furnaces, that it was only a matter of time for its design to be so modified that it could be used efficiently to supply large volumes of air at pressures normally required to drive the machines in common use about a colliery. It has been said that the turbo compressor is nothing like so efficient as a reciprocating compressor, being much less economical in the smaller sizes, and only slowly approaches the efficiency of the reciprocating type as the volume of free air becomes considerable. As matters stand at present there is little doubt that for outputs exceeding 5000 cu. ft. of free air per minute the rotary compressor is a lively competitor with the reciprocating compressor.

Principle of Turbo Compressor. Referring to Fig. 114, which shows a transverse section of a simple turbo blower, it is seen that air enters the rotor in an axial direction at the centre and is caught up by the guide blades which revolve in the direction of the arrow marked "rotation." As the rotor revolves the blades impress upon the particles of air contiguous to them a certain force which causes them to move outwards from the centre at an ever-increasing velocity. This velocity, whatever it may be when the particles reach the periphery of the rotor, may be resolved into two velocities, one in the direction of the radius through the point of exit from the wheel, and the other in the direction of the tangent through the same point. As the particles of air leave the rotor with greater velocity than they had when entering the rotor, it follows that they now possess more energy than previously, but as that energy exists for the most part as kinetic energy, and it is pressure energy that is required for the transmission of power, it is necessary that the velocity of the air should be diminished in some way. Since the total energy in a stream

of fluid is constant, and we may for convenience suppose the wheel to occupy the horizontal position, it follows from the truth of Bernoulli's theorem that diminution of kinetic energy is accompanied by an increase of pressure energy. As the air passes through the whirlpool chamber it is guided by guide vanes through passages between them. As the air

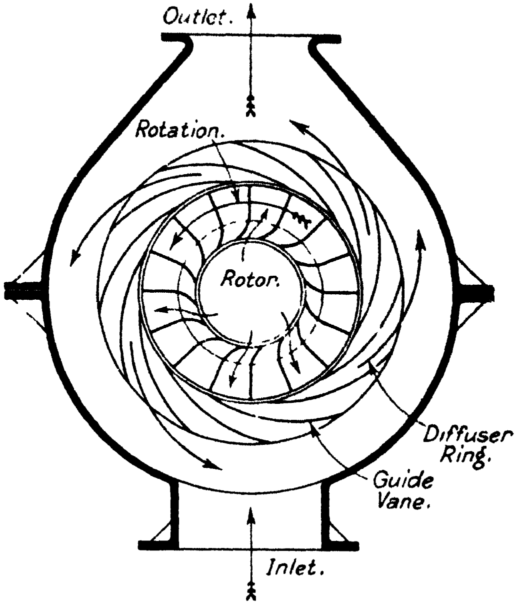
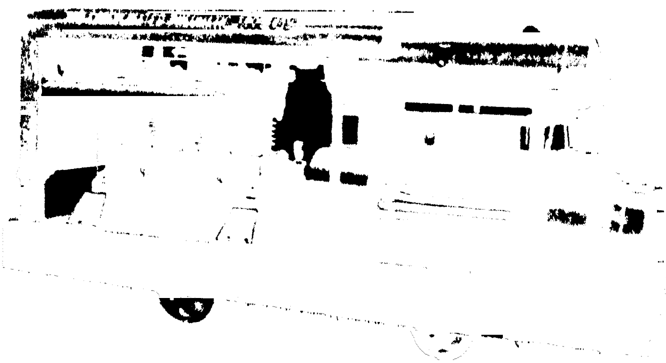


FIG. 114 TRANSVERSE SECTION OF TURBO BLOWER

passes from the inlet to the outlet of the diffuser ring, or whirlpool chamber, its velocity decreases and there is a corresponding increase in the pressure of the air. In order to obtain higher pressures than are obtainable with one rotor, several rotors are fixed on the same shaft, but these are separated from each other by diaphragms fixed to the casing, thus forming individual stages. In each diaphragm an annular guide passage is formed so that the air may be conducted from one stage to the next with a minimum loss of energy by friction.

The compressor is essentially a multi-stage one, and as a rule it is fitted with a water-jacket, and may also be fitted with an intercooling system between stages.

Portable Air Compressors. In modern coal mines the occasion often arises for the use of air-driven machines in mines where power is generally transmitted electrically. When tunnels are to be driven, or coal has to be broken down, holes have to



(The Consolidated Pneumatic Tool Co., Ltd.

FIG. 115. PORTABLE AIR COMPRESSOR

be bored to take the charge of explosive, or to receive a Cardox or Hydrox shell, or to accommodate a Coalburster. That work is done either by means of percussive or rotary drills, and in both cases the supply of compressed air is provided by the installation of portable air compressors near the situation in which the pneumatic tools are to be used. Fig. 115 shows a mine-car compressor which is made in various capacities, the maximum being 350 cu. ft. of free air per minute. It is seen that an a.c. motor, with external cooling ribs, is mounted on the steel car frame and connected direct to the compressor; the receivers being placed above the motor.

The provision of such a machine enables a supply of compressed air to be obtained with a minimum loss of air by leakage, and minimum loss of power by drop in pressure

arising from leakage or frictional resistance of the air passing through the pipes.

Air Pipes. The pipes used in the transmission of compressed air may be made of cast iron, wrought iron, or steel. Wrought iron or steel pipes are to be preferred to cast iron pipes because they are lighter and therefore easier to handle.

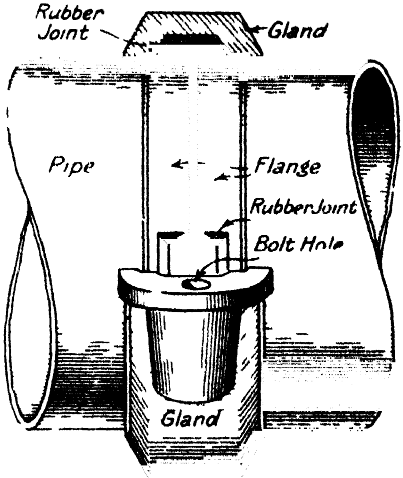


FIG. [illegible]—VICTAULIC JOINT

Cast iron is brittle, and because of that cast-iron pipes are not so strong to resist stresses due to tension and shear as wrought-iron or steel pipes. The main air pipe in the shaft may be installed with such care as to give little trouble, and leakage may be prevented entirely if the joints are welded instead of being bolted. The joints may be welded in the shaft when that is permissible, but should that operation be likely to prove dangerous because of the amount of inflammable gas in the air, the work may be done on the surface. Pipes placed in the shaft, whatever may be their form, must be supported by *collaring* similar to that used in supporting water pipes. The pipes used on roadways are generally connected together by bolted flanges. The flanges on cast-iron pipes are liable

to be broken by rock movements, but the loose flanges on wrought-iron or steel pipes are more tenacious and less likely to be broken. It is especially desirable that the air-line should be flexible to some extent, and that is best secured by the use of a joint that admits of free movement of the pipes within a limited range of angle. The Victaulic joint shown in Fig. 116

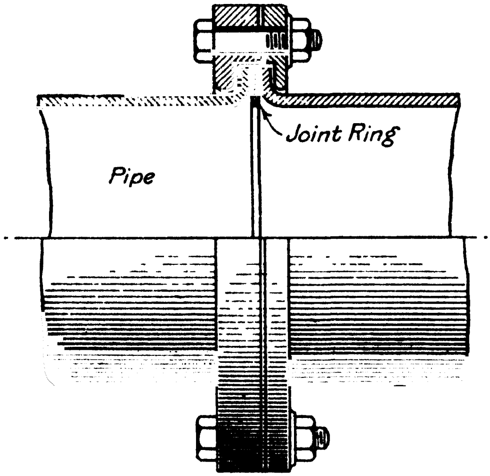


FIG. 117. LOOSE-FLANGED PIPE JOINT

is one that remains air-tight even when the axis of one of the pipes is turned through an angle of 15° from the other. Fig. 117 shows a common form of the loose-flanged joint used to connect wrought-iron or steel pipes.

Pipe Supports. Because it is easy, or convenient, to lay air-pipes on the floor of the mine that is where they are sometimes laid, but those who have had experience of the work of repairing joints in pipes which have become covered with debris, know that it is a much better plan to raise the pipes above the floor, and to support them in such a position that joints can be attended to and leakages discovered. Air-pipes ought to be supported in some such manner as that indicated by Fig. 118, which shows the pipe to be supported on a batten nailed to two props.

Underground Receivers. It is most likely that the compressed air passing down through the pipes in a shaft will have attained the temperature of the outside atmosphere before the bottom of the shaft is reached, provided the shaft is not less than 100 ft. deep; therefore, it is desirable that the earliest

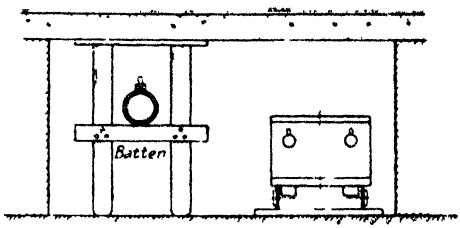


FIG. 118. SECTION OF ROAD SHOWING POSITION OF AIR PIPE

opportunity should be taken to draw off the condensed vapour that will have gathered in the pipes due to the cooling of the air. This is most conveniently done by passing the air into a receiver at the bottom shaft. The water may be run off by hand as it gathers in the receiver or an automatic water trap-

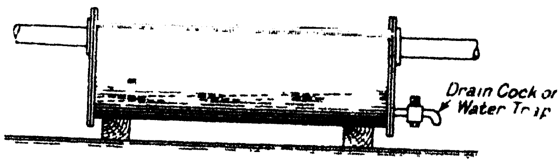


FIG. 119. UNDERGROUND RECEIVER

way be used, the latter device being preferable. The principal use of a receiver is to serve as a means of storing compressed air in such quantity as to prevent violent pulsations of the air in the pipes, and it is for this reason that other, and possibly smaller, receivers should be installed at points adjacent to the engines in which the air is to be used. The receiver acts as a reservoir of power in so far as its capacity enables it to meet sudden demands for power. In order

that it may fulfil that function properly its volume should be at least three times the consumption of air per minute Obviously, inbye receivers may be smaller than that placed at the bottom of the shaft. Fig. 119 shows a suitable arrangement of a receiver in a pipe-line at an inbye position. The air passes into the receiver at the top and leaves it at the top, but the drain-cock or water-trap is attached at the bottom to enable the water to be drawn off periodically. The need for removing water from the air-line is apparent when one considers that the temperature of the exhaust air may be lower than the freezing point.

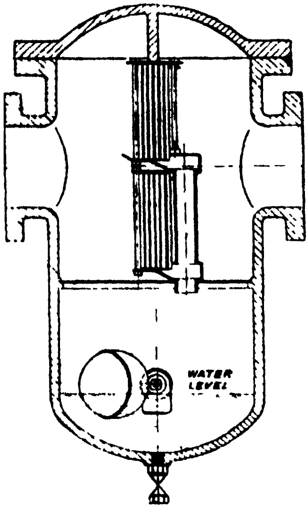


FIG. 120 HUWOOD AIR DRIER

Air Drier. It is usual to supply air-driven engines with air at full pressure for almost the complete length of the stroke, so that there is considerable risk of the interruption of working of such engines unless the air is dried before use or the temperature is increased by preheating. The latter method cannot be used with convenience and safety in coal-mines, but the former method may be employed with advantage. Moisture may be removed from compressed air by passing the latter through such a device as the Huwood air drier. This device consists of a cast-iron chamber in which a number of plates are placed in staggered formation to intercept the passage of moisture which is collected in the bottom of the chamber and automatically discharged from it through the valve in the lower portion of the chamber. Fig. 120 is a section of the drier.

Diameter of Pipes. In considering the diameters of pipes forming parts of a compressed air installation, one may regard

the matter from the point of view of the allowable limit of velocity of the air passing through the pipes, or from the standpoint of the allowable pressure drop over a certain length of piping. Dr. D. Penman suggests the following limits of velocity :-

Main air lines	25 ft. per sec.
Branch pipes	50 ,, ,, ,,
Hose pipes	200 ,, ,, ,,

The imposition of a limited velocity is really directed to the reduction of the loss of pressure by the frictional resistance of the pipes. If we specify the permissible drop of pressure per 1000 yards of piping of different kinds, we may proceed at once to determine the diameter of pipe required to convey the requisite volume of compressed air. The following allowances may be made in the cases of different kinds of piping :-

Main shaft and underground pipes per 1000 yards .	3 lb.
Branch pipes	6 lb.
Small pipes	30 lb.
Hose pipes	60 lb.

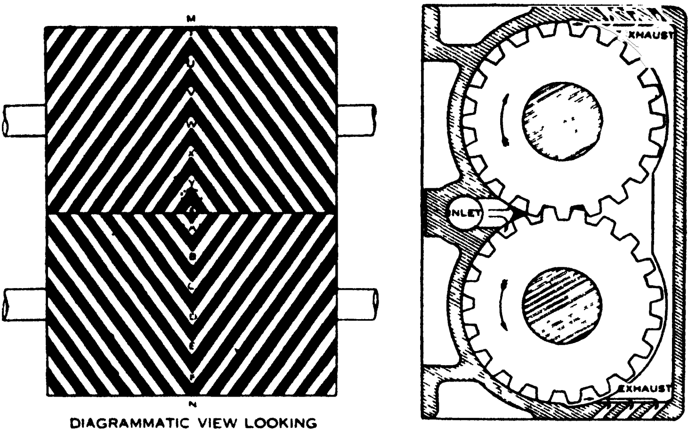
Utilization of Compressed Air. Compressed air may be used direct to raise water from wells or shafts without the use of a machine, or it may be used to actuate pumps, haulage gears, conveyors, and coal cutters, through the medium of air turbines or reciprocating engines.

In confined spaces the air turbine may advantageously be used to drive machines of comparatively small powers, but for higher powers the reciprocating engine may be preferred.

Air Turbine. Some manufacturers of coal-cutting machines have standardized the air turbine as the means of driving coal-cutters where compressed air is used to transmit power. Fig. 121 gives two diagrammatic views of the rotors of the air turbine used by Mavor and Coulson, Ltd., for driving the coal-cutters made by them. The turbine consists of two rotors, upon the cylindrical surfaces of which double-helical teeth have been formed, and the rotors in mesh are housed in twin cylinders, so that the lines of contact between engaging teeth form air-tight joints separating the upper from the lower sides of the rotors. The efficiency of the turbine is maintained by

making the diameter of the rotors a running fit within the cylinders. The rotors are mounted on shafts which run on ball bearings contained in the bearing heads of the casing. The directions of rotation are shown by the arrows in the sectional diagram, and they are not reversible, hence it is necessary to provide reversing gears, which may be made to engage with either of the rotor shafts as required.

Action of the Air Turbine. The air is admitted to the



DIAGRAMMATIC VIEW LOOKING ON UNDERSIDE OF ROTORS

DIAGRAMMATIC SECTION AT M N

(*Mavor & Coulson, Ltd.*)

FIG. 121. AIR TURBINE.

rotors through ports in the underside of the casing, and as the expansion chambers formed between engaging teeth pass the air ports air is admitted to them, and when the chambers have passed the ports the air supply is cut off. At the position of the teeth shown in the illustration the pressure air is being admitted to the space A in which it is imprisoned between the wall of the cylinder and a tooth of the other rotor. The pressure of the air confined in this space forces the teeth apart and so tends to cause the rotors to turn on their shafts. The cumulative effect of expanding air in several compartments is to cause the revolution of the rotors. The exhaust ports are shown near the top of the sides of the housing, therefore it

will be understood that whereas the teeth in the lower portion of the cylinders are under the action of pressure air the teeth in the upper portion of the cylinder are under atmospheric pressure.

In using air turbines it is necessary to ensure the proper lubrication of the rotors, and it is always desirable that the air used should be dry. If single-stage compression is used and no air-driers are installed it is unlikely that air turbines will operate satisfactorily, but if steps are taken to dry the air thoroughly before use the efficiency of the air turbine will be maintained.

Rock Drill. Fig. 122 shows the form of the Holman rock drill, which was originally designed for use on the Rand. Referring to the figure it will be seen that the piston and piston-rod are in one piece, and that provision is made for attaching the drill to the end of the piston-rod, and the hollow piston is designed to slide along a rifled bar which is attached to the ratchet wheel pivoted in the head of the cylinder. When air is admitted to the right-hand side of the piston the latter is projected to the left and the rifled bar is free to rotate while the stroke is made, but when the stroke has been completed and air is admitted to the annular surface of the piston the piston moves towards the right. Since the ratchet wheel is prevented from rotating by a pawl hinged in the cylinder head the rifled bar is also prevented from turning, and therefore during the backward stroke the piston is caused to make a partial turn on the bar as axis. This action is designed to ensure the drilling of a circular hole in which the drill is unlikely to stick. Having regard to the inequality of the areas of the piston ends it will be readily understood that the backward stroke of the piston is effected by a smaller total air pressure than the forward or drilling stroke. As the rock is cut away the machine is fed forward by turning by hand the screw upon which it is mounted. The whole is mounted on a standard or tripod as required.

Two different forms of valve are used, one for steam and the other for air.

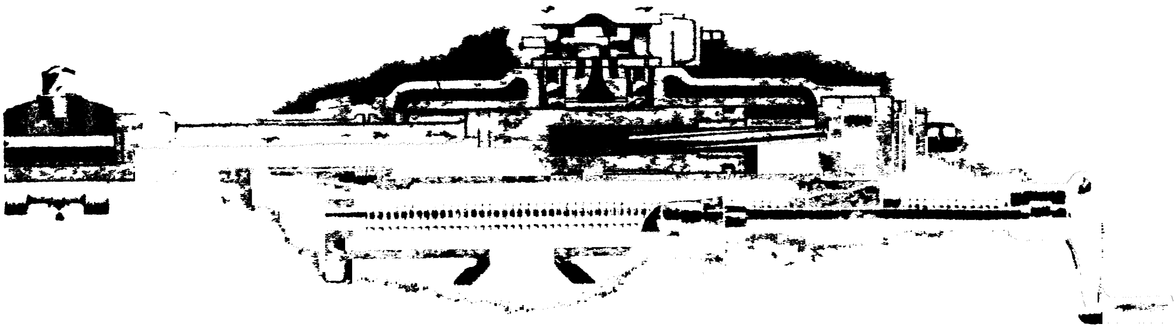


Fig. 1. – Holman Rock Drill

Ball Tappet-valve Drill. This drill resembles that described in every respect except that the form and action of the valve is different. The ball tappet valve shown in Fig. 123 consists of two hard crucible steel balls, a rocker, rocker pin and valve. The figure shows that steam is entering the back end of the cylinder to produce the forward stroke of the piston, and it will be understood that when the piston has moved further

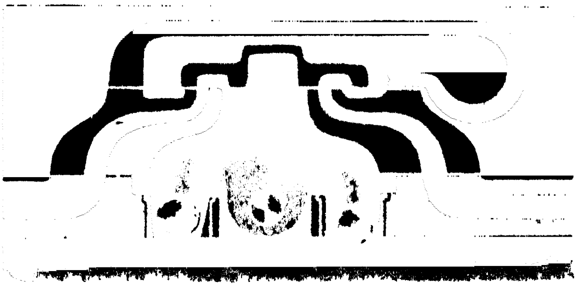


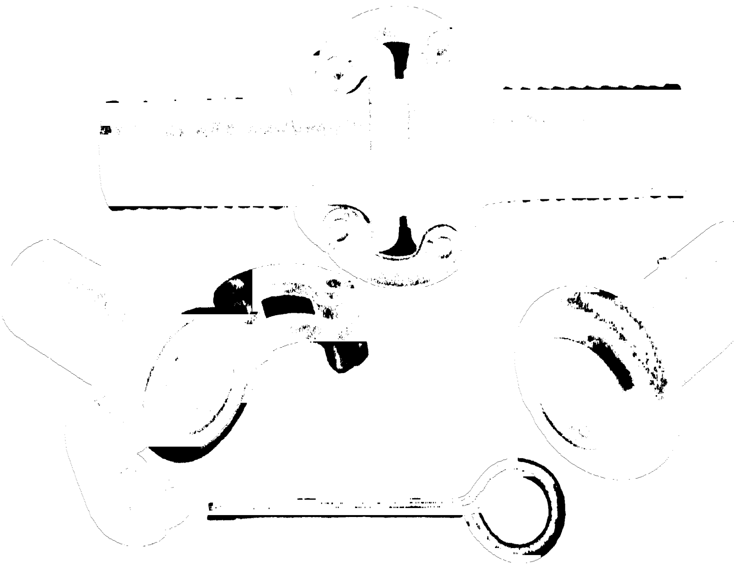
Fig. 123. Ball Tappet-valve Drill

to the left the ball on the right will be lifted and that on the left allowed to fall into the cavity in the piston. In this way the valve is thrown to the left to allow the live steam to enter the lower end of the cylinder, thus propelling the piston on the return stroke. The rocker transmits the motion of the balls to the steam valve. Special features of the ball tappet valve are the absence of jar and the simplicity of action of the mechanism.

Hose Pipes and Hose Couplings. The pipe by which a portable machine is connected to the source of supply of compressed air (or steam) must of necessity be flexible.

Such pipes are made of rubber with cord reinforcement, and they are connected by metallic couplings of some form. Fig. 124 shows the "Gullever" hose coupling produced by Machine Services, Wigan. The coupling is a simple lever joint made by pressing a spigot into a recessed faucet in which a thick rubber ring is fixed. The faucet part carries two cams

pivoted on pairs of links, and the spigot has two lugs in corresponding positions, into which the points of the cams fit. When the spigot is inserted into the faucet, one cam is pressed into position with the fingers and the other cam is pulled over as far as possible with the other hand, then the toggle bar is



(*Machine Series.*)

FIG. 124. "GULLEVER" HOSE COUPLING.

inserted in the hole in the latter, which is prised inwards until it passes over the centre and falls against the spigot part.

In disconnecting the joint the toggle bar is used to prise back one of the cams, and the other is removed by hand. This form of joint has the advantage of being easily and quickly made, and it cannot be otherwise than correctly made, thus preventing leakage of air from the joint.

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EXERCISE QUESTIONS

1 Describe the inlet and outlet valves and seats of the air cylinder of any modern compressor Illustrate your answers by simple sketches (*1st Class Exam* May 1917)

2 An air compressor has one steam cylinder and one air cylinder each 20 in in diameter arranged in tandem (stroke 40 in) The steam pressure is 80 lb per sq in The point of cut off in the steam cylinder is at ½ stroke The steam is not condensed Draw an indicator diagram such as might be taken from the front end of the steam cylinder and another one such as might be taken from the front end of the air cylinder Make the diagrams approximately to a scale of 1 in to 40 lb per sq in (*1st Class Exam* Nov 1918)

3 Describe the purpose and usefulness of an intercooler for a compressor that has compound air cylinders Describe also the general construction and the method of working of an intercooler (*1st Class Exam* May 1920)

4 Draw up an outline specification of an economical steam driven compressed air plant to compress about 2000 cu ft per min of free air to a pressure of 80 lb per sq in for a colliery where the shaft is 250 yd deep including all the plant and accessories wanted for delivering the compressed air to the shaft bottom (*1st Class Exam*, May, 1919)

5. The exhaust ports and passages of plant driven by compressed air sometimes get blocked by ice. How do you explain the presence and formation of this ice, and what steps can be taken to avoid getting the ports and passages choked?

(*2nd Class Exam.*, May, 1916.)

6. A certain volume of air at a temperature of 55° F. is allowed to expand to three times its initial volume. Calculate the temperature of the compressed air.

7. Draw the compression curve given by the law $PV^{1\cdot3} = C$.

8. Calculate the horse-power required to compress 500 cu. ft. of air per min. from 15 to 100 lb. per sq. in. absolute when compression conforms to the law $pv^{1\cdot25} = C$.

9. The clearance in a 10 in. diameter cylinder having a stroke of 14 in. is found to be 27 cu. in. Find the volumetric efficiency when compressing air from 15 to 100 lb. per sq. in. absolute.

10. Draw a sectional sketch of an air compressor and describe the operation of compressing, noting the method of cooling the air, the form and action of the valves, and the method of unloading the compressor.

11. Make a diagrammatic sketch describing the action of a two-stage compressor. What is the reason for "intercooling"? Find the approximate power required to compress up to 600 lb. per sq. in. 20,000 cu. ft. of free air per hour.

12. A two-stage air compressor discharges 305 cu. ft. of free air per min and 1 lb. of water for every 10 cu. ft. of free air is circulated through the intercooler The temperature of the inlet water is 44° F., and that of the water leaving the cooler is 78° F. Calculate the amount of heat abstracted from the air per min., and state its mechanical equivalent.

13. It is proposed to compress air in two stages from 14·7 lb to 100 lb. per sq. in. absolute. Calculate the pressure at the end of the first stage, so that the total work may be a minimum, and the work done per pound of air, assuming that the exponent of the curve of compression is 1·2.

14. State the essential principle of the operation of the turbo compression, and describe the means taken to develop air power in close agreement with the isothermal law.

15. Describe an air hammer drill as used for boring holes in shale or rock. In particular say how the piston is caused to reciprocate and how the drill is caused to revolve.

(*1st Class Exam.*, May, 1917.)

16. In applying compressed air for use underground, what arrangements would you suggest to get the best results and efficiency at various points of use up to 2000 yd. from the shaft bottom? (*1st Class Exam.*, Nov., 1920.)

17 State the circumstances in which you would use an inbye compressor, and give reasons for the infrequent use of compressors in the workings of coal mines

18 Show by one or more hand sketches a loose flange joint for mild steel pipes about 4 in in diameter Give all useful dimensions
(*2nd Class Exam*, May, 1932)

19 Describe with the aid of a sketch a loose flange joint for pipes (say for compressed air) that will allow a slight change in the direction of the axis and remain tight
(*2nd Class Exam* May 1935)

20 An air receiver is about 3 ft in diameter and 6 ft long Make a hand sketch of the receiver showing inlet and outlet branches for the air Indicate also the fittings and mountings that you would have (*2nd Class Exam* May 1935)

21 Give a description of an engine or gear suitable for a main and tail rope haulage system driven by compressed air Describe the controls and give leading dimensions
(*2nd Class Exam* May 1938)

22 You have to lay a line of 3 in mild steel pipes with loose flanges from a tee in a 6 in main along a level course road with bends in it to a definite point Detail the tools and stores you are likely to want for this work (*2nd Class Exam* Nov 1938)

CHAPTER X

STRENGTH OF MATERIALS

THE materials used in mining structures may be fractured by tensile, compressive, shearing, or torsional stresses. When a body is subjected to forces which tend to pull asunder the particles of the body, the stress is tensile, but if the forces are directed in opposition to each other the stress is one of compression. If the forces act in opposite directions and in adjacent parallel planes the material is subjected to shear stress, and if the body is twisted the stress is torsional. The materials used in making a structure will depend on the forces acting on the structure, and as the several parts of a structure may be subjected to different stresses, there may be different materials used in the structure according to their ability to withstand the disruptive forces to which they are subjected. We shall deal with a few simple structures such as are used in mining work.

Strength of a Rod. Let a rod have a cross-sectional area of A square inches, and let it be subjected to a tensile stress of F lb., then since the force tending to fracture the rod equals the force resisting fracture we have $F = S_t A$, where $S_t =$ tensile strength of the material in lb. per square inch. If the load is a stationary one the safe stress f_t may be taken as $\frac{S_t}{6}$, but if the load is a fluctuating one, or is live, the value of f_t might need to be $\frac{S_t}{12}$. If a rod is subjected to an instantaneous stress the stress per unit of cross-sectional area is twice[1] that due to the same load applied gradually. Rods are sometimes used to suspend pumps in sinking pits, and these are formed so that no horizontal section of the rod, or

[1] See *Strength of Materials*, by Prof. Morley, p. 65.

vertical section of the bolts by which they are joined, will be of less strength than the body of the rod itself.

Referring to Fig. 125 which shows a rod joined to a portion of another one by two bolts and two fish-plates, it will be seen that the stress applied to the bolts is a shearing stress, and that there are two planes of shear, therefore if the load F is applied to the rod, the shearing stress applied to each section of the bolt will be $\frac{F}{2}$. The force resisting the shearing force is given by $S_s A$, but the safe stress may either be taken as $\frac{1}{6} S_s$ or $\frac{1}{12} S_s$, according to whether the load is statical or fluctuating.

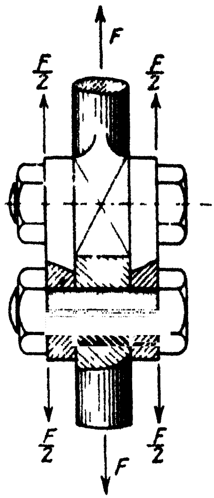


FIG. 125

Example 56. A pump weighing 15 tons is to be suspended from a beam on the surface by means of wrought iron rods of circular section. Calculate the diameter of the rods and bolts, and the size of the fish-plates. $S_t = 50,000$ lb per sq. in.

Solution. $2240F = \dfrac{\frac{\pi}{4} d^2 S_t}{12}$, therefore the diameter of the rods $d = \sqrt{\dfrac{107,520F}{\pi S_t}} = \sqrt{\dfrac{107,520 \times 15}{3{\cdot}14 \times 50,000}}$ $= 3{\cdot}2$ in. The load is taken to be live.

In determining the diameter of the bolts the load on each section of shear is $\frac{F}{2}$, and the shearing stress of the metal is taken as being equal to its strength in compression, i.e. 40,000 lb per sq. in., thus $\dfrac{F}{2} = \dfrac{S_s A}{12} = \dfrac{S_s \times \pi d^2}{48} = \dfrac{40,000\pi d^2}{48}$.

$$\therefore \frac{15 \times 2240}{2} = \frac{40,000 \times 3{\cdot}14 d^2}{48}$$

$$\text{and } d = \sqrt{\frac{48 \times 15 \times 2240}{2 \times 40,000 \times 3{\cdot}14}} = 2{\cdot}53 \text{ in.}$$

If a horizontal section be taken through the bolt-hole of the fish-plate and the greater dimension of the section of the fish-plate is taken to be 5 in., then the effective section will be $3{\cdot}2x$, where x is the thickness of the fish-plate in inches.

$$\text{Now } 12\frac{F}{2} \times 2240 = 3{\cdot}2x \times 22 \times 2240$$

$$\therefore\ 12 \times \frac{15}{2} = 3{\cdot}2x \times 22$$

$$x = \frac{12 \times 15}{2 \times 3{\cdot}2 \times 22} = \frac{180}{140{\cdot}8} = 1{\cdot}3 \text{ in.}$$

Elasticity and Hooke's Law. A perfectly elastic body is one from which all sign of strain would vanish on the removal of the stress. Some bodies recover quickly and some very slowly, but the return to the unstrained condition may be hastened by heat treatment and annealing. Cage chains lose their resilience (power of recovery) and have to be annealed by heating to a cherry red in the forge fire and allowing to cool slowly, or they may be treated in an annealing stove such as is used in foundry practice for annealing castings.

Steel becomes hard when overstrained, and the ultimate tensile strength is increased by overstraining. A body is said to be overstrained when it has been loaded beyond the point at which "stress is proportional to strain," as defined by Hooke's law, and the point at which the proportion no longer holds is called the yield-point. If a load of P lb. be applied to a specimen of length L in. and cross-section A square inches and the extension e in. in the length of the specimen is noted, it will be found that the relation of $\frac{P}{A}$, the unital stress, to $\frac{e}{L}$, the unital strain, is a linear one. The graph of stress and strain is a straight line up to the yield-point, and the quotient of $\frac{P}{A}$ by $\frac{e}{L}$ is the modulus of elasticity of the material in the specimen, thus—

$$\text{Young's modulus of elasticity} = E = \frac{PL}{eA}$$

In testing a specimen of steel 8 in. long and 0·38 in. diameter, a load of 932 lb produced an extension of 0·00174 of an inch, therefore—

$$\text{Young's modulus of elasticity} = E = \frac{932 \times 8 \times 4}{0{\cdot}00174 \times 0{\cdot}38^2 \times 3{\cdot}14}$$
$$= 37{\cdot}8 \times 10^6.$$

From this it will be understood that the material of a structure may be chosen to limit the extension or elongation under the maximum load, and it is by the experimental method of study suggested here that the student will make the greatest progress in acquiring knowledge of the various properties of materials used in constructional work.

Strength of Chains. Chains have many uses about collieries. Heavy cable chains are used to suspend pumps, and short or open-link chains are used in haulage and winding and in various other ways. Such chains are usually made of iron which has been puddled to remove impurities so that it will be capable of standing repeated heatings and hammering without deterioration. Lowmoor and Best Yorkshire still describe the best brands of iron for the manufacture of chains.

A cable chain is distinguished from an open-link chain by the stud placed across the middle of the links to act as a strut, thus preventing the collapse of the sides of the links due to tensile stress. The links of the cable chain are stronger than those of the ordinary form of chain, the diameter of the rod used in making the chains being the same in each case The relative strengths are in the ratio of 2 to $\sqrt{2}$, as determined by destructive tests.

Let d be the diameter in inches of the iron rod used in making chains, and S_t the tensile strength of the material in tons per square inch, then the breaking weight of a cable chain, $W_c = 2\frac{\pi}{4}d^2S_t = 1{\cdot}57\,d^2S_t$, but the breaking stress for a short-link chain, $W_s = 1{\cdot}57\,d^2S_t \times \frac{\sqrt{2}}{2} = 1{\cdot}11\,d^2S_t$. The safe stress may be $\frac{1}{8}S_t$ to $\frac{1}{10}S_t$.

Example 57. Calculate the diameter of rod used in making a cable chain capable of suspending a load of 10 tons with a factor of safety of 8. Assume $S_t = 22$ tons per sq. in.

Solution. $W_c = 8 \times 10 = 1{\cdot}57d^2 \times 22$

$$\therefore\ d = \sqrt{\frac{8 \times 10}{1{\cdot}57 \times 22}} = 1{\cdot}54 \text{ in.}$$

Example 58. A cage containing loaded tubs has a total weight of 12 tons and it is raised by four chains which are inclined at an angle of 30° to the vertical. Calculate the *size* of the chains so that the factor of safety is 10.

Each chain will have to take a quarter of the load, that is 3 tons, but as the chains are inclined to the vertical at 30° as they pass from the top of the cage to the *D*-link, or swivel plate, the oad on the chains will really be 3 secant 30° $= 3 \times \frac{2}{\sqrt{3}} = 3{\cdot}5$ tons. Since the factor of safety is 10, the breaking stress will be 35 tons, therefore —

$$W_s = 35 = 1{\cdot}11d^2 \times 22, \text{ and}$$

$$d = \sqrt{\frac{35}{1{\cdot}11 \times 22}} = 1{\cdot}2 \text{ in.}$$

Handy Rule of Short-link Chains. A rule that is much used by engineers is that the breaking stress equals one-tenth of the square of the diameter in sixteenths of an inch. Calculated in this way the cage chains in the preceding example would be $d = \sqrt{10 \times 35} = 18{\cdot}7$ sixteenths of an inch.

Weight of Short-link Chains. Having regard to the fact that the length of short links is five times the diameter of the rod, the weight of each link and the number of links per fathom could be determined, from which it would be possible to formulate a rule for calculating the weight in pounds per fathom of such chains. A handy rule is: weight in pounds per fathom $= 0{\cdot}21d^2$, where d is the diameter of the rod in sixteenths of an inch.

Strength and Weight of Hemp Ropes.

$$\text{Breaking stress in tons} = 0{\cdot}2 \text{ to } 0{\cdot}6C^2$$

$$\text{Weight in lb. per fathom} = C^2 \div 4$$

where C is the circumference of the rope in inches.

Wire Ropes. Wire ropes such as are ordinarily used in this country are round, but there are still to be found in use at some collieries steel wire flat ropes. The steel used in the manufacture of wire ropes varies in quality, and is described as Bessemer steel, Crucible steel, or Plough steel, but the fact of the matter is that rope makers stock ropes of different sizes in three to five grades of steel and guide ropes for vertical shafts are sometimes made of Swedish or Yorkshire iron. The wires used in rope-making are subjected to tests for strength and ductility. There are three tests of importance: the elongation test, the torsion test, and the flexion test. The strength and ductility of the material depends on the chemical composition and the process of manufacture.

Elongation Test. This test may be carried out in a testing machine so that the stress-strain graph might be drawn to show the relation of stress to strain to enable the modulus of elasticity and elastic limit to be determined, and to enable the ultimate or breaking strength to be found. Much useful work of this kind may be done by suspending two wires from rigid supports, one having a scale of inches attached to it, the other the wire to be tested having a vernier clamped to it so that the extension of the wire being tested may be observed in relation to the scale attached to the index wire. The effects of heat treatment of overstrained iron or steel may be ascertained if specimens of either material are tested when normalized, annealed, tempered, and hardened.

Torsion Test. In this test a length of 100 diameters of wire is taken, and when one end has been fixed in a vice the other end is gripped by a fixture on the end of a shaft that may be rotated until the wire shears off. It is found that the number of turns varies with the breaking stress of the material, the former decreasing as the latter increases, as shown by the figures printed on the next page, Table IV.

Flexion Test. To ascertain the resistance of material to bending stress the flexion test is used. A length of wire is gripped in the vice of a testing machine, the jaws of which are formed by hard steel rollers having a radius of 5 mm.

A hand lever is used to grip the other end of the wire and bend it firmly through an angle of 90° in one direction and then 90° in the opposite direction. The number of such bends required to break off the wire is used as a measure of the ductility of the material. All these tests are capable of being carried out with simple devices to be found in most colliery workshops.

TABLE IV

Breaking stress in tension in tons per sq in	85	95	105	115	125
Number of turns for bright steel wire	36	36	34	32	30
Number of turns for galvanized wire	30	30	25	17	12

Flat Ropes. Flat ropes are made by stitching together several strands of wire each of which is formed of four reddies consisting of seven wires laid on a hemp core. Some idea of the strength of these ropes may be gained by referring to Table V which gives the width and thickness of the rope along with its weight in pounds per fathom and the breaking stress in tons.

TABLE V

Construction 6/4/7

Width	Thickness	Weight	Breaking Stress	
			Patent Steel	Plough Steel
1 11/16	½	6·48	17·76/15·10	21·02/18·63
2	17/32	9·18	24·99/21·25	30·87/26·25
2 9/16	9/16	14·94	40·60/34·51	50·15/42·64
3	⅝	20·34	55·54/47·21	68·61 58·32
3¼	11/16	27·90	76·15/64·74	94·06/79·96
4	13/16	35·94	98·07/83·37	121·15/102·08
4½	1	48·24	131·58/111·84	162·54/138·17

These ropes are extensively used on the Continent and it may be supposed that the following obvious advantages have

had some bearing on the selection of flat ropes, in preference to round ropes, namely: (1) They do not twist. (2) The reel is lighter than any drum that might be used, and consequently starting torque is less (3) Coil friction is reduced and there is no wear due to *angling* on the drum or approaching the pulley on the headgear. (4) The effective diameter of the reels varies inversely as the hoisting proceeds in winding, and therefore the danger from negative load does not arise. (5) Owing to the lightness of the reel and the auto-balance of load efforts, the winding engine need not be so powerful as when heavy drums are used. The comparatively high cost of flat ropes is a disadvantage.

Referring to the last two columns of Table V, it should be observed that the figures given first are those obtained by multiplying the strength of each wire by the number of wires, and the accompanying figures are those determined by actual test, thus showing that the actual breaking stress of a rope is less than the theoretical strength. The same remark applies to round ropes.

Round Ropes. Round ropes are designed in varying degrees of flexibility and of different qualities of steel. In mining we require highly flexible steel ropes for coal-cutters, but haulage ropes need not be quite so flexible because the pulleys round which they pass are usually of larger diameter, and since winding ropes are coiled on large drums and pass round headgear pulleys of similar diameter these ropes may be stil less flexible. The ropes used as guides in the shaft need not be flexible to a great extent and consequently the constituent wires are of larger cross-section than either haulage or winding ropes. There has been steady development in the art of rope manufacture, and much attention is given to the design of ropes with the view of increasing strength per unit of cross-section and presenting the maximum wearing surface so that the life of ropes may be prolonged. The efforts have given rise to the use of different methods of forming and laying the wires and strands in ropes.

Ordinary Lay Rope. Fig. 126 (*a*) shows a rope in which

the wires are laid to the left in forming the strands and the strands are laid to the right in forming the rope. This results in certain wires standing out prominently on the crown of

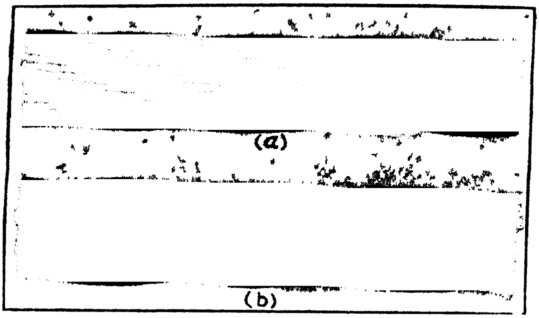
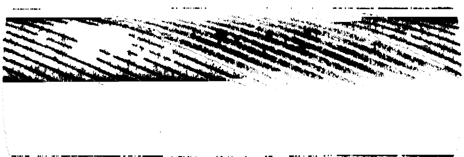


FIG. 126 (*a*) ORDINARY LAY ROPE
(*b*) LANG'S LAY ROPE



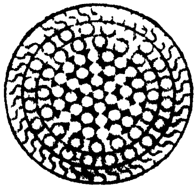


FIG. 127. LOCKED-COIL ROPE

the strands, and as these wires take a large amount of wear they soon break. In forming the rope the strands may be laid on a core of hemp or a strand of wire.

Lang's Lay Rope. Fig. 126 (*b*) shows that the lay of the wires in the strands is in the same direction as the lay of the

strands in the rope, and the result of that construction is that not only is the wearing surface increased but the interna strain is diminished, therefore such a rope wears much better than an ordinary lay rope of the same material. Rarely are broken wires seen.

Locked Coil Ropes. The need for a non-spinning rope in winding and in sinking operations suggested the spinning

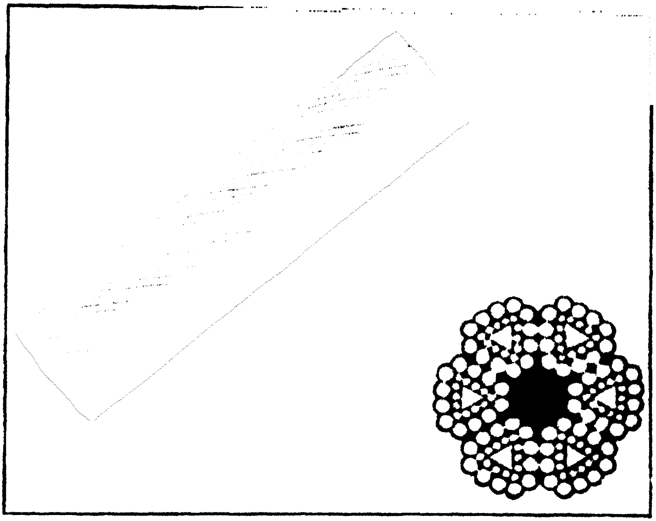


FIG. 128 FLATTENED STRAND ROPE

of a rope in which alternate layers of wire are laid in opposite directions, and the desire to further increasing the wearing surface of ropes led to construction of locked-coil ropes. As seen in Fig. 127, layers of wire are formed round a central strand and the outer surface is just like that of a rod of iron. The rope does not spin and it presents a maximum wearing surface.

Flattened-strand Ropes. The wires forming the strands of these ropes are spun round a central wire of oval or triangular section with the object of presenting a smooth surface having good wearing qualities. Fig. 128 shows that the rope

is made by laying six strands, having an aggregate number of twenty-five wires, on a core of hemp by which the interior wires are lubricated. Since the flattened strand rope can be spliced it may be applied to haulage work, for there is no restriction to the splicing of a haulage rope as there is with respect to winding ropes.

Guides and "Rubber" Ropes. The guide ropes used for guiding the ascent and descent of cages in vertical shafts are placed at the sides of the cages and near to the ends. In addition to those guide ropes other "rubber" ropes are placed between the cages, but not attached to them, so that the cages may be prevented from colliding. These ropes may consist of six half-inch diameter iron wires laid round a central wire of the same diameter, or the locked-coil construction may be used with a smaller number of wires of larger cross-section.

Strength of Wire Ropes. The theoretical ultimate strength of a wire rope may be taken as the sum of the strengths of the constituent wires, whatever their form or the manner in which they are laid to form the rope. Taking a simple case in which there are N wires in a rope, each wire having a diameter of d in., and the ultimate strength of the material being S_t tons per square inch, the theoretical breaking stress of the rope is given by—

$$\text{Breaking stress} = N\frac{\pi}{4}d^2S_t, \text{ and}$$

$$\text{The safe working load} = \frac{N\frac{\pi}{4}d^2S_t}{F}$$

where F is the factor of safety. Now if the safe working load consists of a loaded cage weighing W tons and a winding rope of length D fathoms and a weight of W' lb. per fathom, it is easy to see that

$$F = \frac{N\frac{\pi}{4}d^2S_t}{\frac{W + wD}{2240}}$$

Example 59. A wire rope 1 in. diameter, weighing 10 lb. per fathom, has six strands of seven wires each, the wires being 0·112 in. diameter. The steel in the wires has an ultimate strength of 90 tons per sq. in. What is the factor of safety when a cage weighing 5 tons gross is being raised from a shaft 150 fathoms deep?

Solution.

$$\text{Factor of safety} = F = \frac{6 \times 7 \times 0{\cdot}7854 \times 0{\cdot}112^2 \times 90}{5 + \dfrac{10 \times 150}{2240}} = 6{\cdot}53$$

The number 6·6 is not the real factor of safety for no account has been taken of the influence of the structure of the rope on its strength, or the fact that the load in practice is dynamic instead of static, and consequently there are accelerating and frictional forces which have an important bearing on the margin of safety.

Size and Weight of Wire Ropes. Examination and analysis of the graphs obtained during destructive tests of wire ropes enable certain handy rules to be formulated for finding the size and weight of ropes. It is found that the breaking stress is connected in a simple way to the circumference of the rope and can be expressed as $B_s = KC^2$, where B_s is the breaking stress in tons and C is the circumference of the rope in inches, K being a multiplier which depends on the form of the rope and the material of which it is made. For ordinary ropes the value of K varies from 3·9 to 5·3, the lower value being used when the steel has an ultimate strength of 80 to 90 tons per square inch, and the higher one when the steel has an ultimate strength of 120 tons per square inch. The value of K for locked-coil ropes varies similarly from 4·7 to 6·6 for the same range of tensile strengths.

The weight of ropes of ordinary construction in pounds per fathom is expressed with sufficient accuracy by $\omega = C^2$, but in the case of locked-coil ropes $\omega = 1{\cdot}5C^2$.

Length of Rope that would Break by its own Weight. Obviously, the length of a rope that would break by its own weight depends on the quality of the steel in the rope and on the form of the rope, but for the purpose of this inquiry the case of a patent steel rope may be considered. Let D be the

length of the rope in fathoms; W, the total weight in pounds ($= DC^2$), and B_s ($= KC^2$) the breaking stress of the rope in tons, then—

$$B_s = KC^2 = \frac{DC^2}{2240}$$

$$\text{and } D = 2240K = 2240 \times 4 = 8960 \text{ fathoms.}$$

For greater values of K the limiting length of rope will be correspondingly increased. Now if the factor of safety be taken as 10 the safe working load, consisting of the combined weights of rope, cage, tubs, and coal, in winding must not exceed the weight of 896 fathoms of the rope in use.

Size of a Winding Rope. From the conclusion reached in the preceding paragraph it follows that the circumference of the rope required to raise a given load from a certain depth of shaft is given by the general formula—

$$C = \sqrt{\frac{\text{Load in lb.}}{\frac{2240K}{F} - \text{depth of shaft in fathoms}}}$$

Example 60. A winding rope is to be used to raise a total load of 12 tons from a depth of 400 fathoms with a factor of safety of 10.

Solution Let $K = 4$ and $F = 10$

$$C = \sqrt{\frac{12 \times 2240}{\frac{2240 \times 4}{10} - 400}} = 7 \cdot 3 \text{ in.}$$

Example 61. Calculate the circumference of a locked-coil rope to raise a load of 12 tons from a depth of 500 fathoms. Let $K = 6$ and $F = 10$.

Solution. It will serve a useful purpose to solve this problem by an alternative method involving two expressions of the safe working load, thus—

$$\frac{6C^2}{10} = \text{Load in tons} + \frac{1 \cdot 5C^2D}{2240}$$

$$0 \cdot 6C^2 = 12 + \frac{1 \cdot 5 \times 500C^2}{2240}$$

$$0 \cdot 266C^2 = 12$$

$$\text{and } C = 6 \cdot 7 \text{ in.}$$

Tapered Ropes. The greater the depths from which loads are raised the less does the proportion of load to weight of rope become but if tapered ropes were used the rate at which the proportion varies would be diminished and consequently for a given depth the greater might be the load raised At the cage-end of the rope the only stress is that due to the load, but the stress in the rope at the drum is that due to the combined weights of the load and the rope If C_1 be the circumference of the rope at the cage end and C_2 the circumference at the drum end the former may be found by the simple expression –

$$B_s = KC_1^2 \text{ in which } C_1^2 = W_1$$

and the latter can be found from the modified expression

$$\frac{KC_2^2}{f} = \frac{KW_2}{f} = \text{Load in tons} + \frac{D\left(\frac{C_1^2 + C_2^2}{2}\right)}{2240}$$

or
$$\frac{KW_2}{f} = \text{Load in tons} + \frac{D\left(\frac{W_1 + W_2}{2}\right)}{2240}$$

and since every term except that containing W_2 is known, that can be found hence the value of C_2

Example 62. Calculate the dimensions of a tapered patent steel rope to raise a load of 12 tons from a depth of 400 fathoms with a static factor of safety of 10

Solution. Circumference at the cage end $= \sqrt{\frac{10 \times 12}{4}}$ $= 5.5$ in., and $W_1 = \frac{10 \times 12}{4} = 30$ lb per fathom. Substituting this value for C_1 in the second equation we have—

$$\frac{4W_2}{10} = 12 + \frac{400\left(\frac{30 + W_2}{2}\right)}{2240}$$

$$0.4W_2 = 12 + \frac{400}{2240}\left(15 + \frac{W_2}{2}\right)$$

$$0{\cdot}4W_2 - 12 + \frac{6000}{2240} + \frac{400W_2}{4480}$$

$$0{\cdot}31W_2 = 14{\cdot}68$$

$$\therefore \quad W_2 = 47{\cdot}5, \text{ and } C_2 = 6{\cdot}7 \text{ in.}$$

The weight of such a rope $= \left(\frac{30 + 47{\cdot}5}{2}\right) 400 = 15{,}500$ lb., but the weight of ordinary rope of the same grade of steel would be

$$400\sqrt{\frac{12 \times 2240}{896 \quad 400}} - 400 \times 54 = 21{,}600 \text{ lb.}$$

Strength of Thin Cylinders. Pipes such as are ordinarily used to convey water from pumps, or steam from boilers, are regarded as thin cylinders, and consequently the rules that apply to such cylinders are used to determine the thickness of pipes For equilibrium of forces the bursting pressure should be equal to the resistance of the metal to that pressure, thus—

$$PD = 2t \times S_t,$$

where P is the hydraulic or steam pressure in pounds per square inch; D, the diameter of the pipe in inches; t, the thickness of the pipe in inches, and S_t the tensile strength of the material. If f is the safe stress in the material the equation takes the form—

$$PD = 2tf$$

Example 63. Calculate the thickness of a cast-iron 12 in. diameter pipe to withstand the pressure due to a head of 900 ft. of water, if the safe stress in the material is 2500 lb. per sq. in.

Solution.

$$\text{Thickness of pipe} = \frac{PD}{2f} = \frac{0{\cdot}434HD}{2f} = \frac{0{\cdot}434 \times 900 \times 12}{2 \times 2500}$$

$$= 0{\cdot}94 \text{ in.}$$

Example 64. Calculate the thickness of a main mild-steel steam pipe 22 in. in diameter to convey steam at a pressure of 160 lb. per square inch, if the safe stress is 10,000 lb. per square inch.

Solution. Thickness of pipe $= \dfrac{160 \times 22}{2 \times 10{,}000} = 0{\cdot}176$ in.

Weight of Pipes. In calculating the weight of pipes it is usual to regard the flanges to have a weight equal to that of 1 ft. of pipe. Let D be the external diameter of a pipe in inches, and d the internal diameter, then the volume of metal in 1 ft. of pipe $= \dfrac{\frac{\pi}{4}D^2 - \frac{\pi}{4}d^2}{144} = \dfrac{\frac{\pi}{4}\left(D^2 - d^2\right)}{144}$ cub. ft. When multiplied by δ the density of the metal, the weight per foot of pipe—

$$\omega = \frac{\frac{\pi}{4}\delta\left(D^2 - d^2\right)}{144}$$

Example 65. A cast-iron pipe 12 in. diameter internally has a thickness of 1 in., and the weight of 1 cub. ft. of the metal is 452 lb. Calculate the weight of a pipe 9 ft. long.

Solution.

$$\begin{aligned}\text{Weight of pipe} &= \frac{\pi}{4}\delta(D^2 - d^2)\ (l + 1) \div 144 \\ &= 0{\cdot}7854 \times 452\ (14^2 - 12^2)\ (9 + 1) \div 144 \\ &= 0{\cdot}7854 \times 452 \times 26 \times 2 \times 10 \div 144 \\ &= 1281 \text{ lb.}\end{aligned}$$

The expression may be simplified by working out the constant value of $\dfrac{\pi\delta}{4 \times 144}$ for iron and steel, and the form becomes—

$$\text{Weight of pipe} = C(D^2 - d^2)\ (l + 1)$$

where $C = 2{\cdot}45$ for cast-iron and $2{\cdot}64$ for steel or wrought-iron.

Strength of Thick Cylinder. When the thickness of a cylinder is great compared with the internal radius, as it is in the case of a hydraulic main, in which the pressure may be very great, the thickness can be determined by means of the rule given in *Applied Mechanics* by Perry. When f is the safe stress in the metal; p, the pressure in pounds per square

inch; R_o, the outer radius, and R_i the internal radius, the formula is—

$$f = p \times \frac{R_o^2 + R_i^2}{R_o^2 - R_i^2}$$

Example 66. A cast-iron hydraulic main is to have an internal radius of 2 in. and is to withstand a pressure of 1000 lb. per square inch. Find the thickness of the pipe if the safe stress is 2500 lb. per square inch.

Solution.
$$2500 = 1000 \times \frac{R_o^2 + 2^2}{R_o^2 - 2^2}$$

$$2500R_o^2 - 10,000 = 1000R_o^2 + 4000$$

$$1500R_o^2 = 14,000$$

$$\therefore \quad R_o = 3{\cdot}06 \text{ in.}$$

Case-hardening. It is sometimes requisite that cast-iron and wrought-iron articles should be hardened on the surface and a little beneath to enable them to withstand the wear of surfaces in rubbing contact. The most convenient method of hardening is by the addition of carbon and then quickly quenching from a suitable temperature. In case-hardening, the carbon addition is effected by packing the articles in a box containing suitable substances that are rich in carbon and nitrogen. The most commonly used substances are leather cuttings, horse-hoof parings, potassium ferro-cyanide, and bone charcoal. The box containing the articles and source of carbon is placed in a furnace or stove which is raised to cherry-red heat (about 860° C.) and maintained at that temperature for a period varying from 12 to 24 hours according to the desired degree of case-hardening. The box is then allowed to cool so that the articles may be removed at a dull red heat, after which they are quenched by plunging them in cold water. Those parts which must not be case-hardened are covered with fireclay. When the carbon penetrates to the centre of wrought-iron articles the wrought-iron is converted to steel. When cast-iron is poured into a chilled mould the surfaces of the casting are hardened. Wheels are sometimes made in this way.

Annealing. During the working of metals in forging them

into desired shapes the molecules are forced into unnatural positions and the metals become brittle, but if the metallic bodies are heated and allowed to cool they are brought back to their normal state of plasticity. The process by which the property of plasticity is restored to metallic bodies is called annealing, and the operation may be carried out in the smithy fire, or it may take place in a special stove in which the temperature can be regulated from a red heat to the cold condition. Such stoves are an essential part of the equipment of a foundry or engineering works.

Tempering. Tools used for cutting and drilling rock or metal become blunted and have to be sharpened from time to time. In restoring the cutting edge to the proper shape the metal must be hammered, and in that process the metal loses some of its toughness. The elastic property is restored by heating the article, or that portion of it adjacent to the cutting edge, to about 300° C., and afterwards cooling it in accordance with the quality of the steel and the degree of temper required.

In sharpening a miner's pick the blacksmith first heats the point to a bright red heat, then he hammers the point to shape, after which he again heats the point to a dull red heat and partly quenches the heat to that condition indicated by the colour corresponding to the desired condition. When the desired temper has been obtained the point is quenched suddenly in cold water. The picks used in coal-cutting machines and the twist drills used for drilling holes in coal and rock are tempered in oil, but the cutting tools used in the engineering shop for boring, planing, and turning, are tempered by immersion in oil or a stream of compressed air. Steel in the plastic condition contains free carbide of iron (Fe_3C), but in the hardened state there is little or no free carbide. In tempered steel the condition of the carbon is intermediate between that of hardened and annealed steel. Obviously, the correct temper is that in which the condition of the carbon in the steel is such as to confer on the steel the quality of giving most efficient service.

Welding. The operation by which portions of wrought-iron and steel are firmly joined together is known as welding. In the simplest case the two portions of metal to be welded together are placed in a furnace and heated to a white heat, then the surfaces to be joined have all impurities removed, after which the pieces of metal are hammered together on the anvil. The surfaces are apt to become oxidized in heating and it is necessary to remove the oxidized particles before the pieces of metal can be joined together. This is most conveniently done by throwing sand over the heated surfaces, when the silica (SiO_2) in the sand combines with the oxide of iron (FeO) to form ferrous silicate ($2FeO,SiO_2$), which can be easily shaken from the pieces of metal. Although it is necessary that the pieces of metal should be plastic, care should be taken not to overheat them, for in that condition the metal may become oxidized, or burnt, and unsuitable for welding.

Many of the objects in use about a colliery are unsuitable for welding by hammering, as, for example, the cracked arm of a winding drum, or a cracked cylinder. In order that such pieces of machinery may be efficiently repaired, the oxy-acetylene flame, or electric arc, may be used to cut out the weak portion of the metal and replace the same with sound metal which is made to flow into the space from which the weak metal has been removed. The blow-holes in castings can be efficiently filled up in this way, the holes having been bored out to expose clean metal to the metal to be filled in.

REFERENCE BOOKS

Strength of Materials, by Morley.
Applied Mechanics, by Perry or Duncan.
Textbook of Elementary Metallurgy, by Hiorns.

PAPERS

"Wire Ropes," by Mr. T Albert Taylor, in *Colliery Engineering*, April, 1924

"Research Work in Colliery Roping Steels" in *Colliery Engineering*, May, 1924

"Wire Ropes. Their Construction, Tensile Strength, and Utility," by Mr. G. H. Griffiths, in *The Transactions of the Past and Present Mining Students' Association*, Wigan Mining College.

"Electric Welding of a Cast-iron Rope-drive Flywheel," by Mr. N. E. Webster, in *Trans I.Min E.*, vol. lxii, p. 136.

"The Electric Welding of a Corroded Boiler Shell," by Mr A. Kenneth Dawson, in *Trans I.Min.E.*, vol lx, p 8

EXERCISE QUESTIONS

1. State what you know about the construction, use, and care of wire ropes for winding in shafts (*2nd Class Exam., May*, 1920.)

2. Describe in full detail the operation of sharpening a blunt pick to make it again ready for use.

(*2nd Class Exam., Nov.*, 1918.)

3. What materials would you use for the following parts of machinery? Give reasons for your selection. The bush of a loose drum, a hammer, cage chains, and the remetalling of a bearing. (*2nd Class Exam., May*, 1920)

4. How are the following tests made on individual wires from wire ropes: (*a*) for tensional strength; (*b*) for torsional strength, (*c*) for bending strength? What tensional strength would you expect from the plough steel wire expressed in tons per square inch? (*1st Class Exam., Nov*, 1918.)

5. A wire rope 1 in diameter, weighing 5 lb per yard, has six strands of seven wires each, the wires being 0·112 in diameter. The steel in the wires has a breaking strength of 90 tons per sq. in. Would you regard this as a suitable rope for a loaded cage weighing 5 tons gross in a shaft 300 yd. deep? Show your calculations. (*1st Class Exam, Nov.*, 1922.)

6. State the materials used in the following articles, giving reasons for your choice. State also what you know of the treatment of the materials during manufacture and in use to render and keep them suitable for their purpose: wire for winding and haulage ropes, bridle chains for cages, valve faces and valve seats for steam; screwed and socketed pipes

(*1st Class Exam, May*, 1923.)

7. Describe the processes of welding and of hardening or tempering. Name one metal that can be hardened but not welded, one metal that can be welded but not hardened, and one metal that can neither be welded nor hardened.

(*1st Class Exam.*, Nov., 1913.)

8. What is meant by the terms: tensile strength; torsional strength; elongation; reduction of area; elastic limit, as applied to the testing of materials? How is the knowledge of such properties of metals useful in connection with the plant and machinery of a colliery? (*1st Class Exam., May*, 1914.)

9. State the difference between cast-iron, wrought-iron, and mild steel, and give examples of some articles or parts of machinery that are best made of each of these materials.

(*2nd Class Exam., May*, 1917.)

10. **Describe and sketch in your answer book how you would quickly and efficiently repair the cracked arms of a winding drum.** (*1st Class Exam., Oct.*, 1921.)

N.B. Three of the eight spokes were cracked at about one-third to one-half the distance outwards from the boss, the arms being of T section.

11. Calculate the size and weight of chains suitable for raising a cage having a total weight of 12 tons, these being four chains inclined at 35° to the vertical.

12. If you are handed a round bar of metal 1 in. in diameter and 12 in. long, how would you decide whether the material is cast-iron, wrought-iron, or cast-steel? (*2nd Class Exam.*, May, 1933.)

13. In connection with steel wire ropes for winding or hauling, what can be done in making a wire rope to render it flexible and able to bend round small drums, and what constructions of wire rope reduce spinning in vertical shafts?

(*2nd Class Exam.*, May, 1933.)

14. Design and draw a pin to suit a shackle for a cage chain, providing means for securing the pin in position, and stating the material that you would use. Show all necessary dimensions for making a pin 1 13/16 in. in diameter and 7 in. long.

(*2nd Class Exam.*, May, 1933.)

15. Describe in detail the operation of welding together two round iron rods 1½ in. in diameter to form one straight rod of the same diameter. (*2nd Class Exam.*, Nov., 1934.)

16. State the materials that you would use for the following purposes, giving reasons for your choice: (*a*) A tie rod to carry a pull or tensional stress; (*b*) A column to support a weight or compression stress; (*c*) The body of a valve to sustain a high steam pressure. (*2nd Class Exam.*, May, 1937.)

17. State what is meant by the following descriptions of materials, and name one article for which each material is specially suitable: (*a*) Manganese steel; (*b*) Chilled cast-iron; (*c*) Nickel steel; (*d*) Case-hardened steel.

(*1st Class Exam.*, Nov., 1931.)

18. A steel winding rope is 1¼ in. in diameter, and has a breaking strength of 65 tons. It weighs 2·5 lb. per ft. The loaded cage and attachments weigh 5 tons. The length of the rope from the pit head sheave to the cage at the bottom of the shaft is 900 ft. Calculate the static factor of safety in the rope. If the acceleration is 3 ft. per sec.,^{2} what is the actual factor of safety of the rope at the commencement of the wind?

(*1st Class Exam.*, May, 1932.)

19. Name the metals and metal alloys that are generally used

in the construction of a steam-driven winding engine. Indicate the respective parts of the engine for which each material is suitable and give reasons for your choice

(*1st Class Exam*, May 1933)

20 Give a list of typical wire rope constructions and describe them briefly Indicate the purpose for which each construction is most suitable (*1st Class Exam* Nov 1933)

21 Discuss the use of electric welding in connection with machinery used in and about mines, giving instances of parts now commonly made of mild steel welded, that were formerly riveted or were castings (*1st Class Exam*, Nov, 1933)

22 Make a sketch to illustrate a pin or a rivet in double shear Given that the maximum permissible stress in double shear for an iron pin is 7 tons per sq in of what diameter would you make the pin to carry a load of 6 tons? (*1st Class Exam* May, 1934)

23 Describe the processes of case hardening, hardening, and tempering as applied to steel giving an example of the use of each process in connection with the use of machinery about mines

(*1st Class Exam* Nov, 1935)

24 Write a short account of steel wire winding ropes, dealing with their construction for various duties their handling and care in service and the troubles to which they are liable

(*1st Class Exam*, Nov, 1936)

25 In connection with steel wire winding ropes (*a*) By what process should the steel be made (*b*) What is the common range of strength of wires in tons per square inch? (*c*) By what process is the strength of steel wires attained? (*d*) What tests of wire may be made to show its suitability for use in a winding rope?

(*1st Class Exam* May 1938)

CHAPTER XI

HAULAGE AND HAULAGE APPLIANCES

WHEN the miner has broken down the coal in his working place he may load it directly into tubs, or he may load it on a conveyor by which it is transported along the face to the loading point. The loading point may be situated at or near the face of the working, or it may be arranged that the face conveyor should load the coal on another conveyor working on the road, by which the coal is conveyed to a loader that raises it to the height of the tub and discharges it into the latter. Coal is transported in tubs for some part of the distance between the face of the workings and the shaft, and provision must be made for hauling the tubs towards the shaft. The method used to haul the tubs towards the shafts depends on circumstances, especially with regard to the amount and direction of dip of the beds. In some cases it may be convenient to use gravity or self-acting haulage, but in other cases it may be necessary to apply some mechanical means of hauling the tubs towards the shafts. In any case, it will be necessary to exert some force to control the motion of the tubs, either in holding them back or pulling them forward.

Tractive Force. That force which is required to overcome the frictional and gravitational resistances to the movement of a load on an inclined plane is called the tractive force. Fig. 129 shows a tub at rest on an inclined plane which makes an angle θ with the horizontal plane. Since the tub is at rest under the action of the forces W, R, and T, these forces may be set out in order to form the triangle of forces, from which it is seen that—

$$T = W \sin \theta \text{ and } R = W \cos \theta$$

The force required to overcome gravitational resistance is $W \sin \theta$, but frictional resistance must also be overcome when

the tub is hauled uphill, and the force necessary to do that is $\mu W \cos \theta$, where μ is the coefficient of frictional resistance, thus the tractive force $T = \mu W \cos \theta + W \sin \theta$, but should the load be moving downhill $T = \mu W \cos \theta - W \sin \theta$.

When $\theta = 0°$, $\sin \theta = 0$ and $\cos \theta = 1$, hence, the force necessary to move a load on a level road equals μW. When $\theta = 90°$, $\sin 90° = 1$ and $\cos 90° = 0$, hence the upward vertical pull equals W. It is thus apparent that as the value of θ increases $\mu W \cos \theta$ diminishes and $W \sin \theta$ increases. When the load is moving downhill the term $\mu W \cos \theta$ may or may not be greater than $W \sin \theta$, so that it may be necessary to exert a pull in the downhill direction.

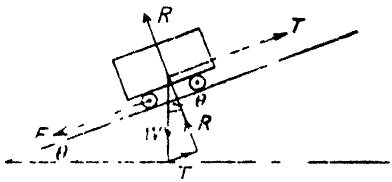


FIG. 120 TRIANGLE OF FORCES

Practical Rules. The inclination of a haulage plane is often referred to in terms of the sine of the angle of inclination, by so many inches to the yard, or 1 in x. Such an expression should not be confused with the *gradient*, i.e. the tangent of the angle of inclination, although there is little difference between them when the angle does not exceed 12°.

If for $\mu W \cos \theta$ we put F, signifying the frictional resistance, and if for $\sin \theta$ we put i, the following handy rules may be written down, viz.: $T_u = F + Wi$ for uphill movement, $T_d = F - Wi$ for downhill movement. If we assume that it is necessary to move a load of 1 ton on gradients of 1 in 10, 1 in 70, and 1 in 100, both uphill and downhill, and K is a constant $(= \frac{1}{70})$ representing average tractional resistance, we get—

$$\text{For 1 in 10, } T_u = F + Wi = WK + Wi = \frac{1}{70} \times 2240 + \frac{2240}{10}$$
$$= 256 \text{ lb.}$$

$$T_d = F - Wi = KW - Wi = \frac{1}{70} \times 2240 - \frac{2240}{10}$$
$$= -192 \text{ lb.}$$

For 1 in 70, $T_u = F + Wi = \frac{1}{70} \times 2240 + \frac{1}{70} \times 2240 = 64$ lb.

$$T_d = F - Wi = 32 - 32 = 0.$$

For 1 in 100, $T_u = F + Wi = \frac{1}{70} \times 2240 + \frac{2240}{100} = 54{\cdot}4$ lb.

$$T_d = F - Wi = 32 - 22{\cdot}4 = 9{\cdot}4 \text{ lb.}$$

These calculations show that when the coefficient of resistance is $\frac{W}{70}$, the gradient of 1 in 70 is *critical* This means that on lower inclinations than 1 in 70 the tubs would have to be hauled in both directions. The negative sign denotes a holding back force to prevent tubs from running downhill out of control on gradients greater than 1 in 70. Obviously, the critical angle is influenced by the coefficient of resistance of the tubs on the track, and that in practice is a varying quantity which depends on the lubrication of the tubs and the state of repair of tubs and track.

Tubs and Lubrication. Tubs may be made mostly of wood or they may be made entirely of iron and steel. They may have a capacity of a few hundredweights, as when the roadways are very low, or they may have a capacity of several tons, when the roads are maintained of sufficient height and width to accommodate them. Now that coal is so much transported by mechanical conveyors, and the number of loading points is consequently reduced, we may see in the future a greater use of the bigger tub. Tubs fitted with plain pedestals are lubricated as they pass across greasers set in the main haulage roads, but the improved type of pedestal, incorporating ball or roller bearings, is designed to carry a quantity of lubricant which is renewed from time to time.[1]

Systems of Haulage. We are chiefly concerned with the various arrangements that are usually made when installing gravity and mechanical haulages. Gravity haulages may be of the intermittent type, in which empty and loaded tubs are

[1] See "Colliery Trams," by J. H. Roberts, B.Sc., in *Colliery Engineering*, June-August, 1927

attached to the opposite ends of a rope passing round a pulley at the top of the incline, or the tubs may be attached to an endless rope which passes round pulleys at the top and bottom of the incline. Several mechanical systems of haulage are in vogue, but we shall deal mainly with direct haulage, main- and tail-rope haulage, endless rope haulage, and locomotive traction.

Gravity Haulage. This system of haulage is operative because the force of gravity acting on the loaded tubs is sufficient to overcome opposing forces of gravity and frictional resistance.

Given that W = weight of loaded tubs in lb. gross

w = weight of empty tubs in lb gross

w_1 = weight of haulage rope in lb.

F = frictional resistance of loaded tubs in lb $= \dfrac{W}{70}$

f = frictional resistance of empty tubs in lb. $= \dfrac{w}{70}$

f_1 = frictional resistance of rope $= \dfrac{w_1}{20}$ lb

In order that the intermittent system of haulage may operate

$$Wi > wi + w_1 i + F + f + f_1$$

$$\text{and } (W - w - w_1)\, i > F + f + f_1$$

$$\text{therefore } i > \frac{F + f + f_1}{W - w - w_1}$$

Example 67. Calculate the least gradient for a self-acting jig upon which it is proposed to run tubs in sets of 8, each tub having a gross weight of 15 cwt when loaded and 5 cwt. when empty. The haulage rope weighs 3 lb per fathom and the incline is 200 fathoms long

Solution.

$W = 8 \times 15 \times 112 = 13{,}440$ lb $F = \frac{1}{70} \times 13{,}440 = 192$ lb.

$w = 8 \times 5 \times 112 = 4480$ lb. $f = \frac{1}{70} \times 4480 = 64$ lb.

$w_1 = 3 \times 200 = 600$ lb. $f_1 = \frac{1}{20} \times 600 = 30$ lb.

$$i = \frac{192 + 64 + 30}{13{,}440 - 4480 - 600} = \frac{286}{8360} = \frac{1}{29 \cdot 2}.$$

Should the gradient of any considerable section of the incline be opposed to the movement of the tubs, the ordinary system would give place to the endless rope system of haulage in order that the resultant pull due to a number of distributed loads

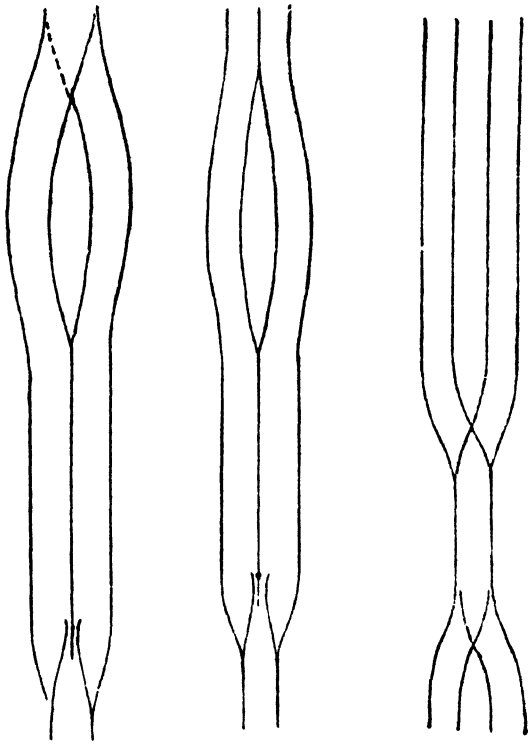


FIG. 130. ARRANGEMENTS OF TRACKS

might be sufficient to maintain continuous movement of the tubs

Arrangements of Tracks. Where the condition of the roof admits of its adoption, the best arrangement is to have a double road from top to bottom. If width of road is a matter of importance there may be three rails above and below the parting or three rails above and a single track from the

parting to the bottom of the incline. These arrangements are shown in Fig. 130. There is little doubt that the double-track arrangement is the best one, for the switches at the top and bottom of the incline are under the care of haulage hands stationed there, moreover, there is no possibility of the loaded gang colliding with the empty gang. Where switches are necessary they should be designed to operate automatically, and they should be guarded against possible displacement by the rope, and it is an advantage to have an electric bell operated by the tubs as they approach the switches so that the

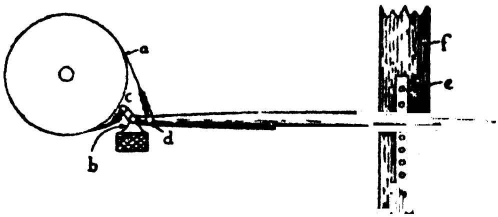


FIG 131 BAND BRAKE

banksman may regulate the speed of the gang entering the switches.

Rope Pulleys and Brake. The pulley at the top of the jig may have the ordinary form of C-groove, or it may be a Thorncliffe pulley having a deep V-groove with sides making an angle of about 17°. Whereas two, or even three, turns of rope may be put on the C-pulley, only little more than half a turn can be put on the Thorncliffe, indeed that will be quite sufficient for most loads. Either form of pulley should have a strap brake like that shown in Fig. 131 attached to it. The strap is made of iron and has attached to it blocks of hard wood, the attachment being made by countersunk bolts.

Safety Appliances. It is essential to have safety catches to arrest runaway tubs in case of the breakage of couplings or rope, or the failure of the banksman to see that all the tubs of a gang are coupled together before removing the scotches on the bankhead. Where possible, the loaded set of tubs should

be attached to the rope *before* the stop-blocks are withdrawn, or, failing that, two sets of stop-blocks such as are shown in Fig. 132 should be installed, so that the lower set would prevent accident in case tubs should not have been coupled before

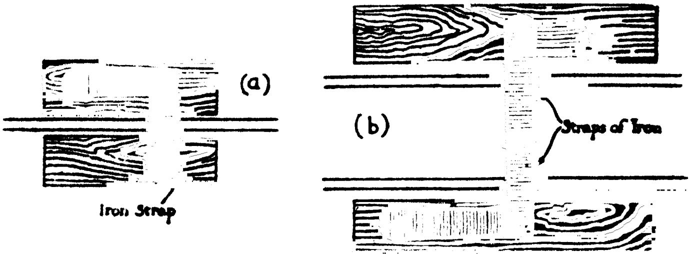


FIG. 132 STOP-BLOCKS

removing the upper block. In the case of the set or gang getting out of control, as in the event of the rope breaking, the runaway set may be arrested by the erection of " warwicks " at several points on the incline. The warwick is

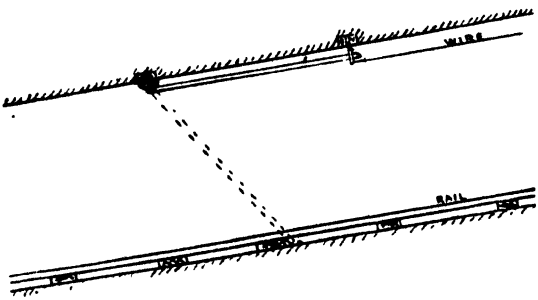


FIG. 133 WARWICK

pivoted to a beam set across the road and let into the sides, and is normally held against the roof by a shackle, as shown in Fig. 133. Should tubs break away the banksman pulls a wire to remove the shackle, and thus allow the warwick to drop into the position shown by the dotted lines.

" Hecla " Runaway Tub Catch. This device is designed for

automatically stopping tubs on an incline, which have got out of control owing to the breakage of the haulage rope, failure of a rope clip, fracture of a drawbar, or the breaking of a coupling. It consists of a strong cast-steel frame supporting two steel rocking levers. These levers project in a slantwise position adjacent to each other. One lever serves to stop a runaway tub travelling in one direction, whilst the other lever performs the same operation on a tub travelling in the opposite

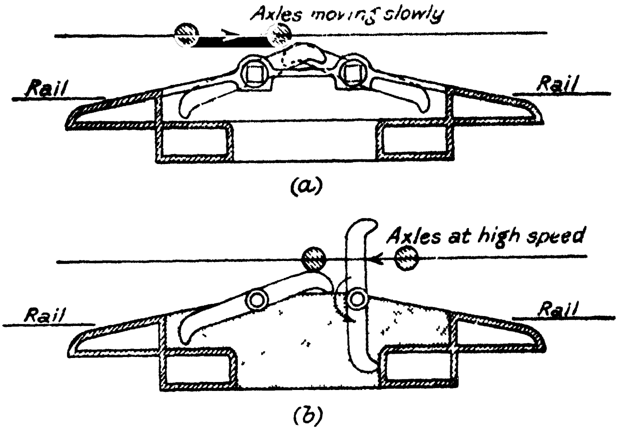


FIG. 134 "HECLA" RUNAWAY TUB CATCH

direction. Fig. 134 (*a*) is a sectional sketch showing the relative positions of the levers and frame when tubs are moving normally at a speed of about four miles per hour over the catch, and Fig. 134 (*b*) shows their relative positions when arresting a runaway tub. Moving at a low speed the axles of a tub merely disturb the levers, but when the speed of the tub is high the impact of the leading axle is sufficient to overturn the lever next the side of approach into the position in which the other axle is caught by it.

When tubs travel uphill in one direction it is only necessary to provide one lever, and that is normally in the position in which a runaway tub would be arrested. An unbalanced lever

is pivoted to an angle-iron frame, and as the tubs pass uphill the lever is depressed by the axles so that when the tub has passed the lever is in position for arrestment of tubs that run away.

Balance Jig, or "Cuddie." When the gradient at the face of the workings is steep, loaded tubs may be lowered singly against the gravitational pull of a balance weight which is arranged to run on a narrow track at the side of the tub track,

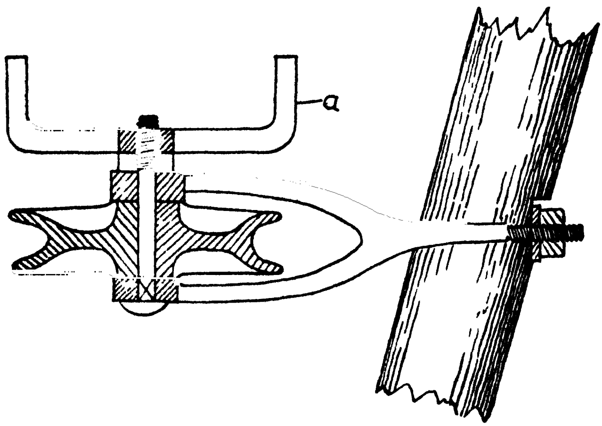


FIG 135. JIG PULLEY WITH BRAKE

or between the rails of the latter. The balance weight is mounted on wheels, and may be arranged to run the whole length of the incline or part of the length. A common form of jig pulley with brake is shown in Fig. 135. Provision must be made at the bottom of the incline for fastening the rope during the removal of the loaded tub and the attachment of the empty one. An iron fork bolted to a sleeper, or other beam, forms a suitable attachment.

Endless-rope Gravity Haulage. When large outputs of coal have to be handled on extensive inclines, there is no system of haulage to excel the endless-rope system. Whether the rope is carried above the tubs or under the tubs depends mainly on whether the tubs are attached to the rope at the top

of the incline or at several points along the incline. If there are several points of attachment, the over-rope system is more convenient than under-rope haulage, but the latter may be used with advantage when the tubs are attached at the top only. In either case the tubs may be attached to the rope by ⅜ in. lashing chains, even on steep gradients. A double track is laid from top to bottom of the incline, and a Thorncliffe or a Clifton fleeting pulley, of which Fig. 136 is a part section, is placed at the top of the incline, preferably in the horizontal position. The rope is also passed round a plain pulley of similar diameter at the bottom of the incline, and it may be arranged to function as a tension arrangement by mounting the frame on wheels and applying a balance weight to it. The tubs may be attached singly, or in sets, at regular distances along the rope, and in order that the hanger-on may know when to attach tubs a signalling device, operated by the tubs last attached to the rope, is placed in a convenient position at the requisite distance from the loading point. If loaded tubs and empties are attached simultaneously they will be equally spaced. The endless-rope system of haulage, when running at low speeds, is capable of delivering a large output of tubs to the bottom of the incline, irrespective of the length of the plane, and since the speed is low, the cost of maintaining the rolling stock and track in efficient condition is also low in comparison with that of the ordinary system

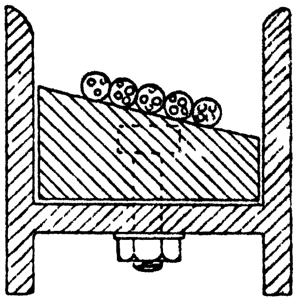


FIG. 136. CLIFTON PULLEY

Carriage Inclines. In working highly-pitched seams it may be necessary to use carriages for the purpose of lowering tubs from one level to another. Carriages are designed to hold the tubs in the horizontal position, and are balanced by a weight mounted on wheels running on a narrow track beside the tub track.

Main-rope Haulage. This system of haulage is applicable to the case in which the dip of the haulage road is such as to cause the empty tubs to gravitate towards the workings and drag the haulage rope after them, so that the loaded tubs may then be hauled outbye by a compressed air engine, a steam-engine, or an electric motor, placed near to the point of delivery of the tubs. If the point of delivery is inbye the power is most likely to be transmitted by compressed air or electricity, preferably the latter if it is permissible to use electricity in the mine. In this system a single track is necessary, and the engine is provided with one drum loosely fitted to the drum shaft but connected to it by means of a block or claw clutch. A suitable post brake or strap brake is applied to the drum to control the descent of the empty tubs. When a steam or compressed air engine is used to drive the haulage, a single reduction gear is fitted, but a double reduction gear is usually fitted when the drive is electrical. The speed of main-rope haulage depends on the condition of the track and tubs and on the power supplied, and the power supplied depends on the output required, or, more precisely, on the tractive force and the speed of the haulage. The horse-power of the engine or motor is expressed thus -

$$\text{h.p.} = \frac{\text{tractive force in lb.} \times \text{max. speed in ft. per min.}}{33{,}000\,E}$$

where E = the efficiency of the haulage gear.

Example 68. What power must be supplied to drive a haulage gear capable of dealing with an output of 300 tons in 8 hr. from a down-brow dipping at 1 in 10 for a distance of 500 yd? The maximum speed should be 8 miles per hour, and the efficiency of the gear may be taken as 0·7. Gross weight of tub, 15 cwt; tare, 5 cwt.

Solution.

Time to make double journey $= \dfrac{500 \times 3 \times 2 \times 60}{8 \times 5280} = 4{\cdot}3$ min.

Time to change at the end = allowance $= 5{\cdot}7$ min.

Total time = 10 min

Number of journeys per shift $= \frac{8 \times 60}{10} = 48$

Number of tubs per journey $= \frac{300 \times 20}{48 \times 10} = 13$

Weight of 13 loaded tubs $= \frac{13 \times 15}{20} = 9.75$ tons

$= 21\,840$ lb

Tractive force to haul tubs $= Wt + F$

$= \frac{21,840}{10} + \frac{21,840}{70}$

$= 2496$ lb

Assuming that the factor of safety of the rope is 7 and that the breaking stress is expressed by $3C^2$, we can find the circumference and weight of the rope

$$\text{Breaking stress in tons} = \frac{7 \times 2496}{2240}$$

$$C^2 = \frac{7 \times 2496}{3 \times 2240} = 2.6$$

and the weight of the rope is 2.5 lb per fathom or 625 lb in all, hence the maximum tractive force at the beginning of the trip is expressed by

$$T = Wt + F + w_1 t + f_1$$

$$= 2184 + 312 + \frac{625}{10} + \frac{625}{20}$$

$$= 2590 \text{ lb}$$

$$\text{H.p. of engine or motor} = \frac{2590 \times 704}{33\,000 \times 0.7} = 79$$

When the grade is uniform the motor may be series wound, as this form of winding gives the maximum torque at starting and runs well at uniform load, but we have seen that it tends to race on light load In deciding on the type of motor, due regard must be paid to the possibility of the tubs having to be started from rest on the incline

This system of haulage may also be used to haul empty tubs up headings and to control the descent of loaded tubs by means of the brake

Main- and Tail-rope Haulage. Fig 137 is a diagrammatic

representation of this system of haulage, and it shows that the main rope is used to haul the loaded tubs outwards to the engine, and the tail rope to haul the empty tubs inbye. Such a system of haulage seems desirable when it is only possible to have a single track laid in a road in which the gradient may be opposed to the tubs passing in either direction. As it is sometimes necessary to haul coal from different districts with the same gear, arrangements are made at the junctions of the roads leading to the districts whereby the ropes in the branch roads may be coupled to the main ropes. Fig. 138 shows an arrangement of this kind. When the empty gang arrives at the position shown in the figure, the tail rope *e* is detached from the front of the gang and the branch rope *f* is coupled to the first tub. The tail rope is also disconnected at *d* so that the other end *c* of the branch rope may be connected to the tail rope. When the loaded gang arrives at the same point, the branch rope is detached, and the tail rope passing round the terminal pulley is coupled to the tubs, after which the journey is continued to the shaft landing. The main rope is carried on rollers placed between the rails, and where curves have to be negotiated bevel pulleys may be placed between the rails or at the side of the track near the inner rail. The tail rope may be carried on rollers placed on the floor at the side of the track, or it may be carried on wheels attached to props set at the side of the track. The terminal pulley may be placed vertically or horizontally, as shown in Fig. 139. The haulage gear is provided with two drums, and both of these are provided with clutches and brakes so that each may be driven by the engine or motor, or controlled by the brake attached to it.

Air-driven Main- and Tail-rope Haulage Gear. As the workings of a mine are developed it sometimes becomes necessary to install auxiliary haulage gears of this type, to be driven either electrically or by compressed air. In either case the drums must be actuated through gearing, and some form of clutch to enable the driving mechanism to be connected to either drum as required. Fig. 140 shows the general arrangement of an air-driven gear made by Walker Bros., Wigan.

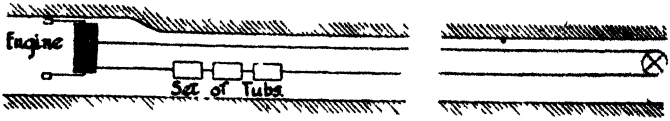


Fig. 137. Main and Tail-Rope Haulage

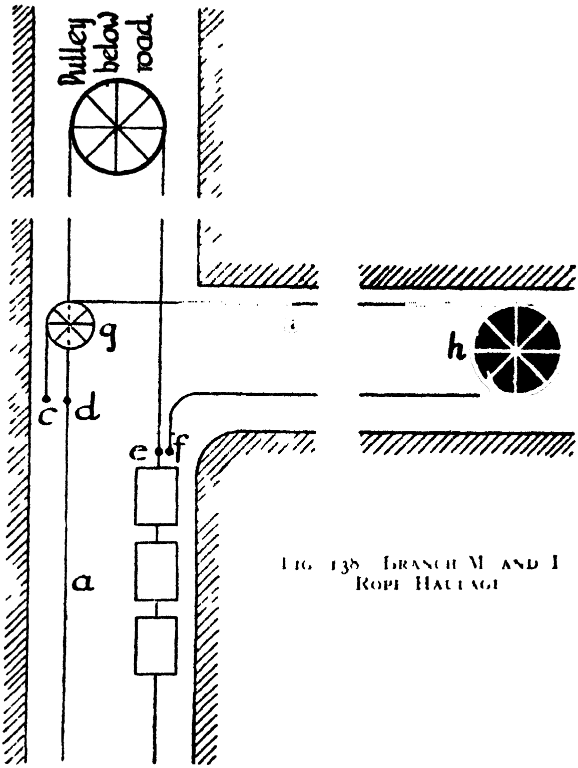


Fig. 138. Branch M. and T. Rope Haulage

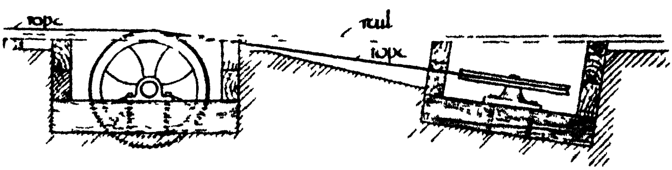


Fig. 139. Terminal Pulley

The engines are of the self-contained type, with two cylinders each 6 in. diameter by 8 in. stroke. The cylinders are made of hard cast-iron, and the pistons of the Ramsbottom type are also made of cast-iron, the piston rods being made of mild steel. The valve gear is of the open-exhaust piston type, and it will be seen on referring to the illustration that the valves are operated by connecting rods attached to linkwork of the Hackworth type. The framework is built up of steel plates and rolled-steel joists, and the cylinders, bored crosshead

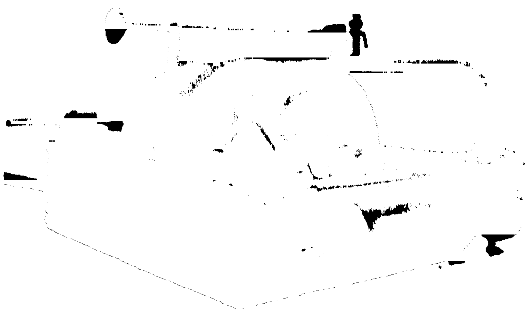


FIG. 140. AIR-DRIVEN M. AND T. HAULAGE GEAR

guides, and pedestals are bolted to it. The crank and second-motion shafts are made of mild steel, and a high-carbon steel pinion on the crank-shaft meshes with the spur wheel on the drum shaft. The drums are provided with band brakes, and are actuated by cast-steel claw clutches; the positions of the levers being seen in the figure. The drums are 18 in. diameter and 15 in. wide, with side flanges 6½ in. deep, each being bushed with brass and bored for running loose upon the shaft. A special feature of this gear is the open-exhaust valves by which the trouble arising from ice in the exhaust ports is avoided.

Power Calculations. The power required to drive a main- and tail-rope system of haulage must be such as to give the requisite speed on the steepest grade opposed to the traction of the loaded tubs

Example 69. A haulage road is 1300 yd long and has an average gradient rising inbye for a distance of 900 yd, after which the road dips at 1 in 10 for the remaining length of 400 yd. An output of 400 tons of coal per shift of 8 hr has to be hauled in tubs having a capacity of 10 cwt of coal and weighing 5 cwt empty. If the speed of the haulage is 10 miles per hour calculate the main dimensions of a steam engine having two cylinders to operate the haulage with an efficiency of 0.7 and a steam pressure of 60 lb per sq in.

Solution

Speed of haulage $= \dfrac{10 \times 5280}{60} = 880$ ft per min

Time to make double journey $= \dfrac{1300 \times 3 \times 2}{880} = 9$ min

Time to change sets = allowance $= 6$ min

Total time $= 15$ min

Number of journeys per hour $= 4$

and the number of tubs in each gang

$$= \frac{400 \times 2}{8 \times 4} = 25$$

Tractive force on 1 in 10 $= \dfrac{25 \times 15 \times 112}{10} + \dfrac{25 \times 15 \times 112}{70}$

$= 4200 + 600$

$= 4800$ lb

If the factor of safety is 7 and the breaking stress of a patent steel rope is expressed by $4C^2$, the breaking stress of the rope is $7 \times \dfrac{4800}{2240} = 4C^2$, therefore $C^2 = \dfrac{7 \times 4800}{4 \times 2240} = 3.7$. The weight of the rope having a length equal to twice the length of the plane $= \dfrac{1300 \times 2 \times 3.7}{2} = 4810$ lb, and its frictional resistance may be taken as $\dfrac{4810}{20} = 240$ lb. The tractive force exerted by the engine equals $4800 + 240 = 5040$ lb and, since the speed of the haulage is 880 ft per min, the units of work done per minute $= 5040 \times 880 = 4{,}435{,}200$ ft-lb.

If we assume that the speed of the pistons is limited to 250 ft

per min., we may state the equation of work and find the diameter of the cylinders, thus—

$$2 \times \frac{\pi}{4}d^2 \times P \times S \times E = \text{units of work}$$

$$2 \times \frac{\pi}{4}d^2 \times 60 \times 250 \times 0{\cdot}7 = 4{,}435{,}200$$

$$d^2 = \frac{4{,}435{,}200}{2 \times 0{\cdot}7854 \times 60 \times 250 \times 0{\cdot}7}$$

$$\text{and } d = 16{\cdot}4 \text{ in.}$$

If the length of the stroke is proportioned to the diameter of the cylinder, in accordance with usual engineering practice, it should be the next bigger standard size to $\frac{2{\cdot}5 \times 16{\cdot}4}{12} = 3{\cdot}4$ ft.

When an electric motor is used to drive a main- and tail-rope haulage, the horse-power[1] of the motor is based on continuous rating and equals $\sqrt{HP_l^2 + HP_e^2}$, where HP_l is the horse-power applied to the traction of loaded tubs and HP_e is that spent in hauling empty tubs

Modified Main- and Tail-rope Haulage. A useful modification of the system is that in which one rope passes round a shallow-grooved pulley to the terminal pulley and back to the front of the ingoing gang of tubs, the other end of the rope being attached to the back end of the gang. The haulage gear is necessarily reversible, the reversal being effected by the introduction of a reversing switch in the circuit of an electric motor or valve gear of a steam or air-engine.

Endless-rope Haulage. In this system of haulage a wire rope passes from the haulage gear to a return pulley at the inbye end of the plane and back to the fleeting pulley of the gear, which may be driven either by steam, air-power, or by electricity. The haulage gear may be placed on the surface or it may be placed at the bottom of the shaft, or if the system is auxiliary to the main haulage it may be placed inbye, the power being transmitted in accordance with the power used. Several arrangements may be used according to circumstances and these are—

1. Driving gear on the surface with the rope passing down the shaft and round as many branches as there may be.

[1] *Electrical Practice in Collieries*, by Prof. Burns (page 220).

2. Driving gear on the surface with band rope transmitting power to a clutch gear at the bottom of the shaft.

3 Driving gear at the bottom of the shaft driving the clutch gear there.

4. Driving gear placed above, the power being transmitted by pipes or cables

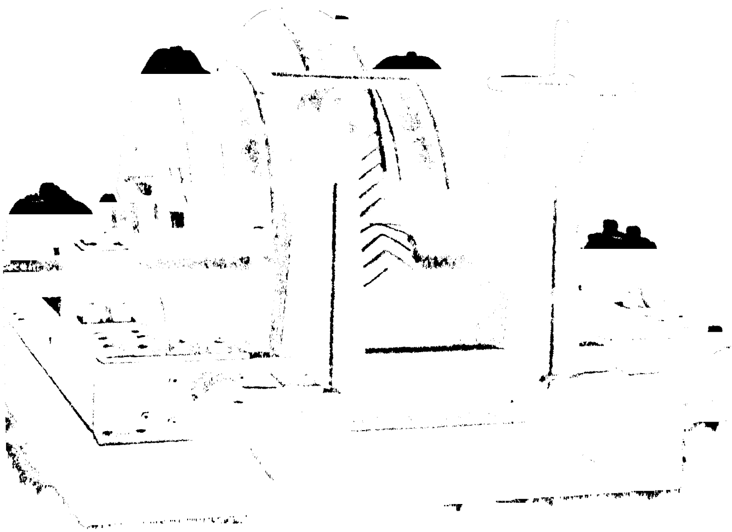


FIG 141 CARRON ENDLESS ROPE HAULAGE GEAR

5 Branch haulages may be driven by clutch gear operated by the main haulage rope acting as a band rope

Fig. 141 shows a double endless rope gear as made by the Carron Company, Carron, Stirlingshire, and it consists of two fleeting pulleys driven electrically, first through belting, and then by double helical spur gear and wood-lined friction clutches. The regulating screws for operating the clutches are supported by strong brackets, having swivel nuts of gun-metal. Each drum has attached to it a strong wood-lined brake worked by a foot-tramp The plummer blocks are of the

double oil-ring, self-oiling type, and are provided with gun-metal bushes. The bed-plate consists of steel girders bolted together. The same firm makes heavier gears in which the speed is reduced by treble-reduction gear after the initial belt drive, or by worm gearing in which there is a phosphor-bronze worm working into a cast-iron worm wheel. The spur gear is made of cast steel with machine-moulded teeth

Tension Carriages. Owing to the continued stretching of haulage ropes and the fluctuating nature of the load, it is

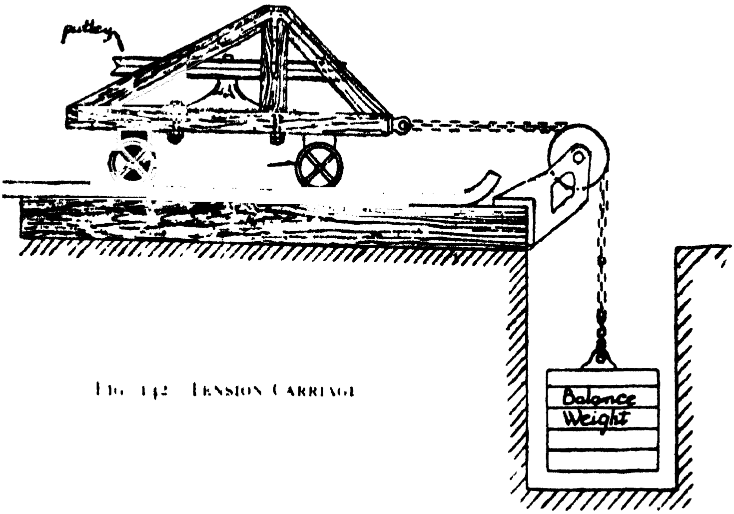


FIG. 142 TENSION CARRIAGE

necessary that the slack should be taken up by a tension arrangement of some kind. Fig. 142 shows a tension carriage with balance weight attached. Such a device is usually placed near to the driving gear so that the rope passes directly from the tension carriage to the driving pulley, thus ensuring that the conditions required by the expression $\frac{T_1}{T_2} \quad E^{\mu\theta}$ shall always be fulfilled. If the tension carriage is placed on an inclined plane, the balance weight may also be mounted on a carriage of similar construction.

Operation of Branch Haulages. When it is desired to work branch haulages at the inbye end of a main haulage, a clutch gear is installed in the vertical position, as shown in Fig. 143, or it may be mounted on a horizontal shaft and placed in a suitable position near to the termini of the main and branch haulages. The figure shows a main shaft *S* supported on a foot-step *l*, and having the fleeting pulley *n* rigidly attached to it. The driven pulleys marked *o* are connected to the driving shaft by means of the friction clutches marked *p*.

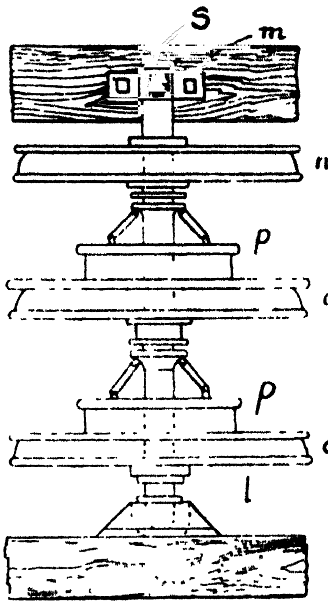
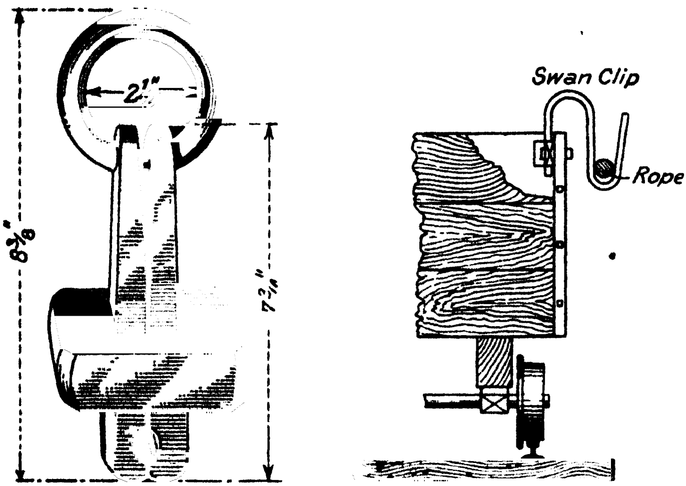


FIG. 143 CLUTCH GEAR

Methods of Attaching Tubs to Rope. The form of attachment used depends on the position of the rope relative to the tubs, and as the rope may run (*a*) over the tubs, (*b*) under the tubs, or (*c*) at the side of the tubs, there is a great variety of clipping devices used to attach the tubs to the rope. There is no more satisfactory method of attaching tubs to an *over-rope* than by lashing chains made of ⅜ in. round iron and 6 to 9 ft. long, these being attached to both ends of the tub, or gang of tubs, where there are reversals of dip on the haulage road When the rope is placed under the tubs, the latter may be attached by means of bogie clips, Smallman clips, or by Fisher clips like that shown in Fig. 144 (*a*), and when the rope is placed at the side of the tubs attachment may be effected by the simple form of Swan clip shown in Fig. 144 (*b*).

Pulleys at Curves. Guide pulleys must always be placed at

curves to keep the rope as nearly as possible in the line of motion of the tubs. When the rope runs under the tubs, bevel pulleys are placed between the rails, but when the rope travels above the tubs and lashing chains are used, a few mushroom pulleys are attached by inverted pedestals to beams placed across the haulage road. Guides are sometimes placed in close proximity to the sides of the wheels or to the



(*a*) FISHER CLIP (*b*) SWAN CLIP

FIG. 144

body of the tubs to prevent derailment of the tubs as they pass round the curves.

Tractive Force. Since the number of empty tubs is ordinarily equal to the number of loaded tubs attached to the rope, it is clear that their gravitational pulls balance, but the frictional resistances are opposed to the motion of the system. The same may be said of the rope, and consequently the tractive force necessary to maintain steady motion of the haulage is given by—

$$T = Wi + F + f + f_1 - wi$$
$$= (W - w)i + F + f + f_1$$

With this difference the calculations for power of motor or dimensions of engines are similar to the examples which have been given in this chapter.

Locomotive Traction. This system of haulage has been extensively employed in America and on the Continent, both electric and compressed air locomotives being used on main haulage roads and in gathering tubs from the working places to the ends of the main haulage systems. Electric locomotives may be worked by the trolley and overhead wire system or by means of storage batteries, although in this country the operation of General Regulation 136 (*a*) prohibits the use of the former type in coal mines. A few locomotives[1] of the latter type are now in use in this country, and as rapid advances are being made in the methods of transporting coal underground, we may see a more extensive use of the storage battery-locomotive. The following particulars relate to a Jeffrey locomotive recently installed in a North Country colliery.

1. The weight of the locomotive is 8 tons.
2. The gauge of the track is 21½ in.
3. The track is laid with 45 lb per yd rails.
4. Sleepers are put in at 2 ft. 6 in. intervals.
5. The average speed at work is 8 miles per hour.
6. The locomotive is driven by two 15 h.p. series wound motors.
7. There are two Exide-Ironclad batteries, each with forty-eight cells divided into two compartments.
8. The batteries have a capacity of 387 amp. hr., and are charged on alternate shifts in an underground station.
9. The tractive force at the drawbar is about 2500 lb. on a level road.

Compressed air locomotives are designed to take supplies of compressed air in steel cylinders at a pressure of about 1000 lb. per sq. in., the air being passed through a reducing valve before being admitted to the cylinders. Compressed air mains are taken along the main haulage roads and connections are

[1] "Storage Battery Locomotives in Mine Service," by A. W. Brown, A.M.I.E.E., vol. lxxiii, *Trans.I.Min.E.*, page 126.

made at certain points along the pipes, so that the locomotive may be connected at convenient points when air is required.

A Modern Arrangement. At a colliery recently visited by the author the coal is loaded on face conveyors, by which it is transported along the face to road conveyors, and then it is conveyed through the motive zone of subsidence to a loading conveyor, by which it is filled into tubs that pass as a continuous train under the discharge of the loader.

Beside the loading conveyor is placed a small, electrically-driven, main-rope haulage gear which is used to lower the tubs in sets of twelve to the siding on the main level. The tubs are hauled to the shaft by an electric locomotive that deals with an output of fully 250 tons of coal per shift of 8 hours The advantages of such a system are

1. The number of loading points is small.
2. Labour is centralized and supervision simplified.
3. Datalling costs are diminished in proportion to the length of roadway to be maintained in condition suitable for the transport of coal and the circulation of air.
4. The transport of coal to the shaft is expeditious
5. Material and stores are conserved.
6. When the coal has been filled on the conveyors there is no need for tubs being handled by men.
7. The cost of production is maintained at the lowest possible level.

Signalling on Haulage Planes. Signals may be transmitted mechanically or electrically, or by such a mechano-electrical method as the Davis-Fryar in which the completion of the circuit is effected by the closure of an oil-immersed switch operated by a balanced wire running along the side of the plane. The limit of electrical pressure operating a signalling device in a fiery mine is 25 volts, and to avoid open sparking at contacts these must be suitably enclosed. Water-tight and flame-proof ringing keys get over that difficulty. Bells are worked by batteries of Leclanché cells and the current is transmitted by bare galvanized iron wires 6 or 8 in. apart, and supported on earthenware insulators

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See also "Underground Haulage," by Mr. J. Beckett, in *The Mining Electrical Engineer*, July, 1926.

EXERCISE QUESTIONS

1. Design a simple metal frame with spindle to carry a sheave, 9¾ in. diameter and 2¼ in. wide, for a tail-rope suitable for attachment to the road timbers. Scale, half size.
(*2nd Class Exam.*, May, 1920.)

2. Make a sketch, with approximate dimensions, of an ordinary pedestal suitable for a haulage engine drum shaft 6 in. in diameter. State of what metal the various parts are made.
(*2nd Class Exam.*, Oct., 1921.)

3. You have a jig wheel, 4 ft. diameter, at the top of a self-acting incline (not endless rope). The rope goes 2½ times round the wheel. In case the full wagons were pushed into the incline without the empty tubs being attached, what safety device would you adopt to prevent the full tubs from getting out of control? Sketch the wheel and frame, and the method of securing it.
(*2nd Class Exam.*, Oct., 1921.)

4. Explain in detail and sketch the arrangement of the wire ropes on the engine in the two cases of (*a*) a main- and tail-haulage system; (*b*) an endless rope haulage system.
(*2nd Class Exam.*, May, 1922.)

5. Where men ride to and from their work on riding trolleys in a main haulage incline, what precautions would you take to

prevent the trolleys breaking loose? Sketch roughly the kind of trolley you would use for riding the men

(*2nd Class Exam*, May, 1922.)

6 Describe with sketches the various arrangements you could use at the top of inclines to prevent tubs inadvertently running down (*2nd Class Exam*, May, 1923)

7 Describe an endless-rope haulage engine, driven either by electric motor or by compressed air engine, as you may choose If the wire rope is 1 in in diameter, what diameter would you adopt for the fleeting wheel? Describe the construction of the fleeting wheel in detail (*2nd Class Exam*, May, 1932)

8 Describe an endless rope haulage engine, the power being either steam or electric (*2nd Class Exam*, Nov 1933)

9 Describe a main and tail-rope haulage engine, driven either by compressed air or electric motor In particular describe the drum and the drum controls (*2nd Class Exam*, May, 1935)

10 Describe a fleeting (Surge or Clifton) wheel for an endless-rope haulage, giving dimensions, and state the diameter of steel wire rope for which your fleeting wheel is suitable

(*2nd Class Exam* Nov 1936)

11 Write a short essay on colliery tubs dealing with the design of body underframe, drawgear and wheels axles and bearings from the points of view of convenience safety in handling and long life (*2nd Class Exam* May 1937)

12 Give a description of an engine or gear suitable for a main- and tail rope haulage system driven by compressed air Describe the controls and give some leading dimensions

(*2nd Class Exam* May 1938)

13 Tubs are often subject to rough usage underground Describe a type of tub designed to give good service Mention the troubles that may be encountered and the means taken to overcome them (*2nd Class Exam*, Nov 1938)

14 Describe the apparatus that you would expect to find in an electrical haulage gear house for working, controlling and protecting the motor What are the essentials of flame-proof switch-gear? (*1st Class Exam*, May 1931)

15 An output of 500 tons of coal is to be delivered up an incline 700 yd long, dipping 1 in 8, laid with two tracks in tubs holding 20 cwt, in 7 hours by direct two-rope balanced haulage, the power being steam at about 80 lb per sq in Describe the haulage engine that you would install, giving the chief drum and cylinder dimensions. (*1st Class Exam*, May, 1931)

16 An incline 500 yd long, dipping 1 in 4, is laid with a single track. Tubs are to be hauled up the incline in sets of eight, using

a wire rope ¾ in. in diameter, weighing 1 lb per ft. The tubs tare 600 lb. and carry 1200 lb. of coal. The output in 7 hours is to be 150 tons.

State what diameter of drum you would adopt, what would be the full speed of the tubs, and calculate the b.h.p. of an electric motor to work the haulage. (*1st Class Exam.*, May, 1933.)

17. An electric one-rope endless haulage is installed in an incline for bringing up loaded tubs of coal and lowering empties. The motor full-load rating is 100 b.h.p., but the normal load is 90 b.h.p. Describe the arrangements that you would make for controlling this haulage system, especially for stopping and starting.

(*1st Class Exam.*, May, 1937.)

CHAPTER XII

WINDING AND WINDING APPLIANCES

THE term *winding* denotes the operation of raising coal from the bottom of the shaft to such a height above the surface as is necessary to admit of the coal passing by gravitation from the tippler, through the screening plant, to the truck. The shaft is fitted with guides of wood, iron or steel, to ensure that the cages carrying the loaded tubs can be moved at a brisk speed without the risk of colliding with the shaft sides or with each other. The cages are raised by steam or electric winders by means of steel ropes, and to ensure that the operations may be carried out in safety certain auxiliary appliances to be described are used.

Cages. Cages are generally made of wrought-iron or steel, and of such a size and arrangement as to enable the requisite number of tubs to be carried and handled with expedition. Cages should be as light as possible, consistent with strength, hence the use of steel for the main stanchions. They are of necessity fitted with gates, of the collapsible or sliding-bar pattern, and the sides are enclosed by steel sheeting, as shown by Fig. 145, which represents totally enclosed double-decked cages to carry two tubs on each deck. On the side of the cages are to be seen two sets of guide shoes, one for rope guides, the other for the rigid guides at the landings on the surface and at the bottom of the shaft. The cages are also fitted with catches to prevent the tubs leaving them as they are passing up and down the shaft. One form of catch consists of a bar of circular section that is hinged on the side of the cage, and is provided with handles at either end. As the handles are at right angles to the length of the bar, they enclose the tubs when they are turned down to the horizontal position. The form is not a good one, for it is so easy for the hanger-on to fail to place the catches in position before signalling to the

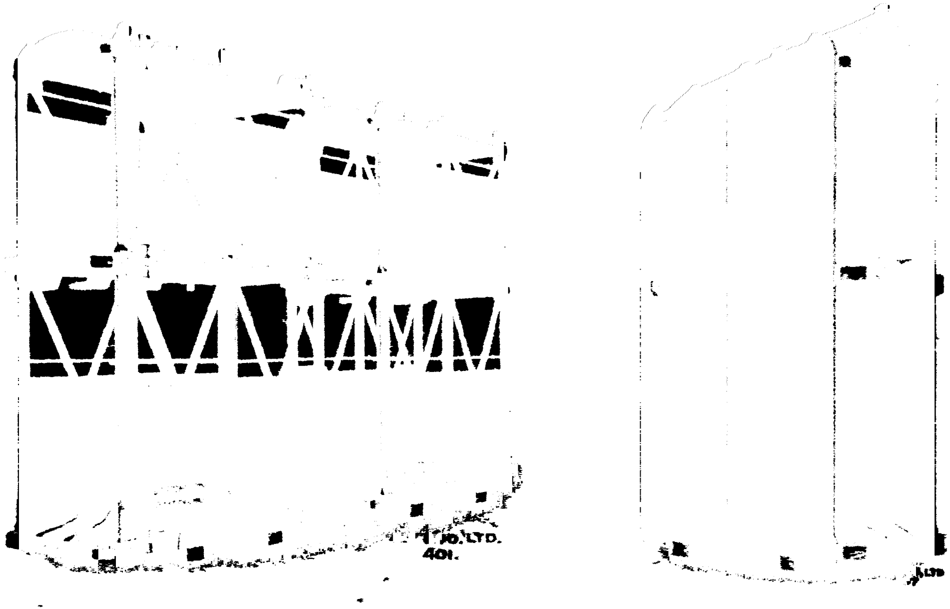


FIG 145. DOUBLE DECK CAGES

winder. Fig. 146 shows a much better arrangement of catches that act on the axles of the tubs. These may be made quite automatic in action by arranging that they are operated by contact with the keps at the top of the shaft and the landing

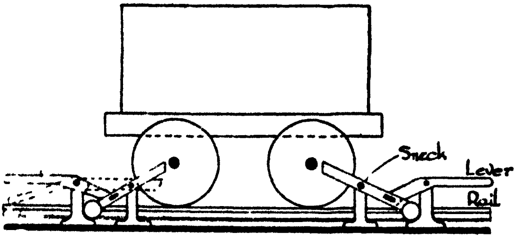


FIG. 146. CAGE TUB CATCHES

at the bottom. The bottom of the cage is sometimes provided with a tilting device which operates the catches, tilts the floor, and ensures that the tubs are changed quickly. The cages are attached to the winding ropes by means of six chains. Four of the bridle chains are in constant use, but the two chains attached to the middle of the sides of the cages act as safety chains. These chains must be annealed from time to time to restore the iron to its initial elastic condition When rigid guides are used the cages are fitted with appropriate shoes, which in the case of wooden guides may extend to the full height of the cages.

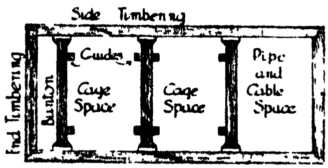


FIG 147 ARRANGEMENT OF WOODEN GUIDES

Wooden Guides. Fig. 147 shows a common arrangement of guides in a rectangular shaft. The guides are made of pitch pine of rectangular section, 4½ in. × 4 in. or 4½ in. × 5 in., the greater dimension being the width of the guide. The normal length is a multiple of 6 ft., and is usually 24 or 30 ft., for they are attached to wooden buntons placed across the shaft at intervals of 6 ft., and it is an advantage to have the

joints made against the solid backing of the buntons. The guides are jointed in the manner shown in Fig. 148, which depicts a *butt* joint secured by four counter sunk bolts and a *scarf* joint secured by three C.S. bolts, with fish-plates covering the joints. An improvement is effected in the butt joint by making a mortice and feather of square form 1 in. × 1 in. from the front to the back of the guides Fig. 149 shows three methods of fixing the guides to the buntons, the angle-iron fixture being the best of all. Due to the vibratory stresses applied by the cages to the guides, the bolts or wood screws soon break at the junction of the guide and bunton and repairs have to be made Having had intimate experience of shaft repairs, the author favours the angle-iron fixture as the simplest for making immediate repairs The woodscrew

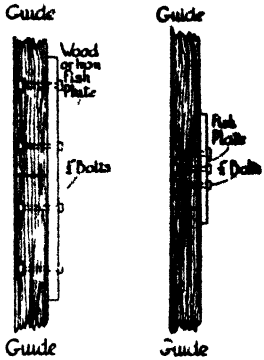


FIG 148. BUTT AND SCARF JOINTS IN GUIDES

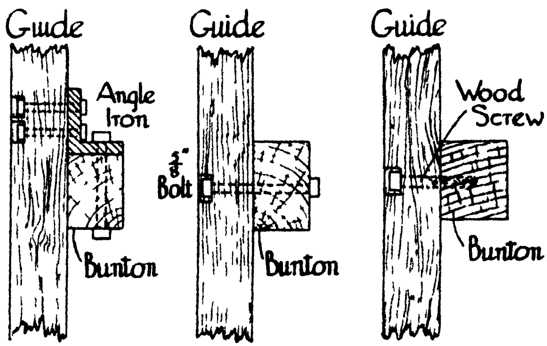


FIG 149 ATTACHMENT OF GUIDES TO BUNTONS

fixture is unsatisfactory because when it breaks the part left in the bunton cannot be removed, and a new hole has to be bored through the guide and into the bunton, thus weakening both.

Cage Shoes for Wooden Guides. The shoes used for wooden guides are made of cast-iron, and are bolted to the sides of the cage, as shown in Fig. 150. They are sometimes chamfered

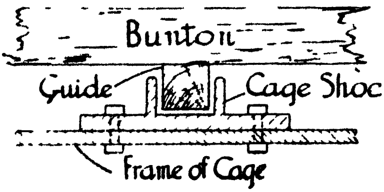


FIG. 150 CAGE SHOES FOR WOODEN GUIDES

at the upper and lower inner edges to prevent them from cutting into the guides at the joints and thus weakening the joints

Rail Guides. A great many shafts are fitted with rail guides, for in addition to being rigid they are stronger than

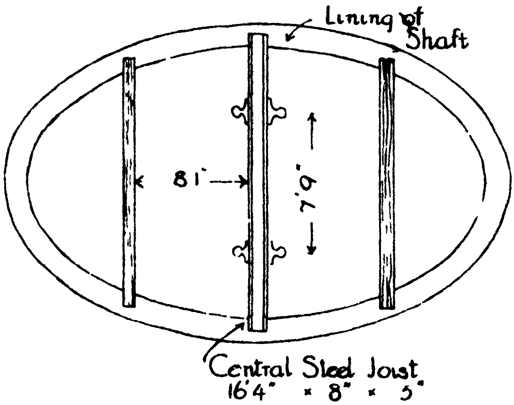


FIG. 151 ARRANGEMENT OF GUIDES IN AN ELLIPTICAL SHAFT

wooden guides, and because of their form they need not be placed on both sides of the cages. Fig 151 shows an arrangement of such guides in an elliptical shaft, but the guides may be attached to the outer buntons so that the space between

the cages may be clear. Fig. 152 shows a common method of attaching the guides to the buntons, but it is obvious that in removing a rail from the shaft for the purpose of replacing it, it would be necessary to undo all the bolts, but if the *chair* was made so that the clip on one side was made removable repairs could be effected with greater speed. It is important that these fixtures should be capable of holding each rail in place without the weight of one being transmitted to another. Alignment may be maintained by dowel pins set in one end of each rail registering with corresponding recesses in the rails opposite. When the speed of winding is high frictional resistance is reduced by the use of a double-roller shoe attached to the cage, and the risk of impact at joints is eliminated by the use of a shoe like that shown in Fig. 153.

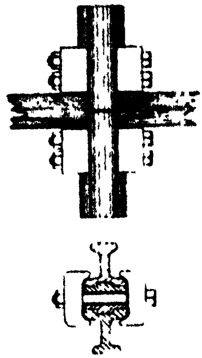


FIG. 152 SHOWING METHOD OF ATTACHING RAIL GUIDES TO BUNTONS

Rope Guides. When shafts are spacious, as in the case of circular shafts, there is no better method of guiding cages than by flexible guides, provided care is exercised in placing the guides in position and maintaining them in a state of constant tension. They are said to be more costly than wooden guides in first cost, but there is no doubt that they are much less costly to maintain in good condition. They can certainly be installed with much less difficulty than iron or steel rail guides, and they are at all times most suitable for winding at high speeds. Fig. 154 shows three forms of rope guides, two of them being of locked-coil construction. Guide ropes may be from 1 in.

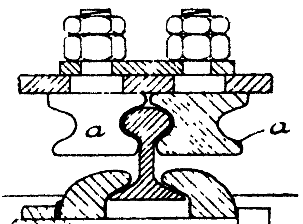


FIG. 153 DOUBLE ROLLER SHOE

to 2 in. in diameter, depending on the depth of the shaft and the loads applied to them. The following particulars relate to an installation of guide rods in a shaft 1000 yd. deep—

Number of conductors	8
Circumference of conductors	5 in.
Type of conductors	locked coil
Weight per fathom	37 lb.
Total weight on each conductor	$8\frac{1}{4}$ tons
Breaking stress of each conductor	88 tons
Factor of safety	6 tons
Material	mild steel

In addition to the guides already mentioned, there are two rubbing ropes between the cages, each $6\frac{1}{4}$ in. in circumference,

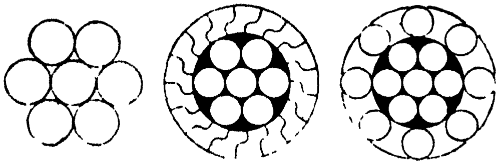


FIG. 154 FORMS OF ROPE GUIDES

and weighted to the same extent as the conductors. Having regard to the equality of vibration in ropes of the same material and equally weighted, it has been suggested that the weights hung on the guide ropes should differ in order that the ropes might vibrate at different rates, and therefore tend to neutralize the tendency to oscillation of the cages, and thus avoid collision of the cages. Such a contingency may be prevented by the suspension of the guides in the positions shown in Fig. 155, where there are four guides to each cage and two rubbing ropes between the cages, the latter having rubbing pieces attached to them.

Methods of Suspending and Weighting the Guides. Guide ropes are suspended from the headgear by means of clamps resting on the cross beams, and they are weighted at the bottom of the shaft by applying cheese-weights to a rod with foot-step attached by a capping to the guide rope as shown in Fig. 156. The ropes are also fastened by clamps to the baulks below the cage landing at the bottom of the shaft.

Cage Shoes for Rope Guides. Fig. 157 shows one form of shoe such as is attached to the cages for the purpose of securing the latter to the guide ropes. Bushes *c* of cast-iron, brass, or

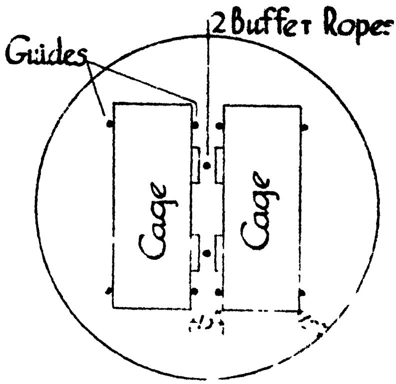


FIG. 155 ARRANGEMENT OF ROPE GUIDES

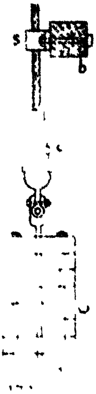


FIG. 156 METHOD OF WEIGHTING GUIDE ROPES

gun-metal, surround the guide rope, and these are fastened by a strap *d* that is secured to the base-plate *a* by the rivets *e*. The length of the shoes should be about twelve diameters of

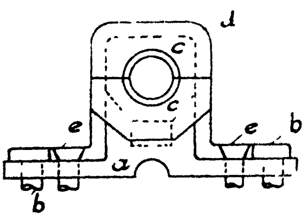


FIG 157 CAGE SHOE FOR ROPE GUIDES

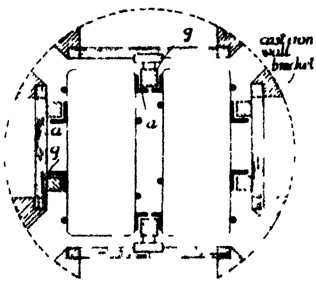


FIG. 158 RIGID GUIDES AT LANDINGS

the rope, and there should be two shoes to each rope. A simpler form of shoe is made entirely of wrought-iron, and consists of two pieces, one riveted to the cage and the other bolted to it.

Rigid Guides at Landings. It is necessary that the cages should pass into rigid guides when it is desired to change tubs from the cages to the landing or vice versa. These rigid guides are attached to buntons or bearers placed across the shaft, and extend from below the shaft mouthing to some distance above the normal position of the cages. Similar guides are

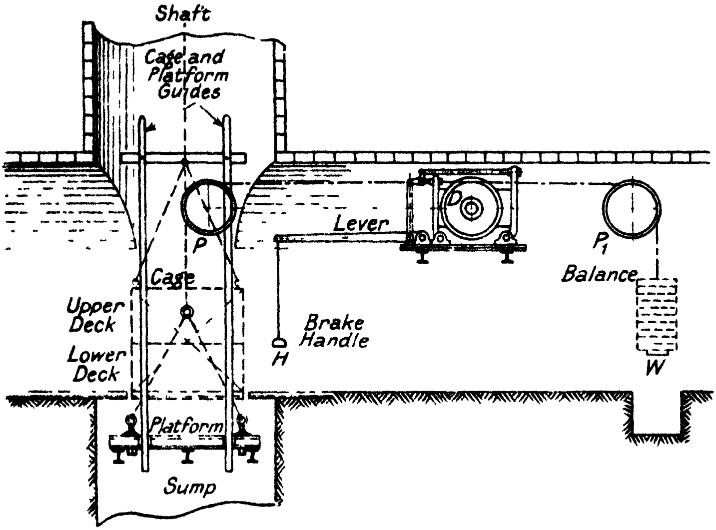


FIG. 159. BALANCED PLATFORM

provided at the surface, and these extend from under the shaft collar up into the headgear to the top of the cage frame. Fig. 158 illustrates such an arrangement as might be provided at the bottom of the shaft. The ends of the vertical wooden guides are tapered to facilitate entrance to the angle or channel guides attached to the sides of the cages.

Balanced Platform. Fig. 159 shows an auxiliary cage or platform that is sometimes used at the bottom of shafts in which the winding cages have more than one deck. Such a balanced platform is used to enable the changing of the tubs at the bottom of the shaft to be carried out independently of

the operations at the surface. The platform runs in the same rigid guides as the cages, and is suspended by two ropes that pass over pulleys P at opposite sides of the cage spaces, then a few times round the flat grooved pulleys D and over the other pulleys P_1 to the back-balances W. The balance is sufficiently heavy to raise the empty balanced platform and the motion is controlled by the brake on the pulley D, the brake being operated by the hanger on at the handle H, which is placed in a convenient position. While the winding cages are running in the shaft the hanger on releases the brake and allows the platform to rise to the level of the mouthing to

FIG. 160.—[illegible]

receive the cage with the empty tubs. With the platform in this position the empty tubs on the bottom deck of the winding cage are replaced by loaded tubs from the mouthing, then the platform is allowed to descend till the upper deck arrives at the level of the mouthing when the tubs are changed as before, the whole operation being in the hands of the hanger on and independent of the decking of the cage at the surface. Obviously the decking at the surface must also begin with the lower deck, so that the operations may be independent of each other and the system may be applied to decking of cages with two or more decks.

Winding Ropes and Cappings. The strength and construction of ropes have been treated of in Chapter X, and it only remains to add that winding ropes are attached to the bridle chains of cages by means of a capping of some form. Fig. 160 shows a common form of capping for use with winding ropes. It consists of a wrought iron or steel loop that has been forged out of a length of square bar iron to form a conical socket for the conical formation on the end of the rope. In capping the

rope it is bound with copper wire for a length equal to that of the capping, a like length of the rope being left unbound at the end of the rope. The wires at the end of the rope are cleaned and opened out, and after having been cut to various lengths they are bent back over the bound portion to form a conical termination. The binding rings are then slipped over the end of the rope, and when the capel has been placed in position the rings are hammered down into position one after the other until the rope has been gripped firmly in the capel. Tests have proved the capel to be quite as strong as the rope. The conical termination may also be formed without bending back the wires, by wrapping them in the same way and cleaning

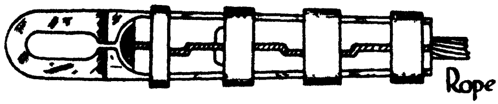


FIG. 161 RELIANCE CAPEL

them with some neutral cleanser such as petrol. The brush of wires is then placed in a mould and white metal is poured into the mould to form the cone, which when cold is placed in the capel and secured in position by the rings. The latter form of capel is strong and possesses the advantage of being easily made and renewed.

" Reliance " Capel. This is a very efficient and simple form of capel. As is shown in Fig. 161, it consists of a loop similar to the last, between the sides of which two wedge-shaped pieces of iron are placed to grip the rope. Clamping rings are driven over the capel to tighten the sides of the loop on the wedges, and when the load is applied the wedges are still further tightened as they are moved towards the open end of the capel. The wires need not be opened out at the end of the rope, but a block of white metal may be cast on the projecting end of the rope to give added strength and to enable the movement of rope in the capel to be observed from time to time.

Socket Capel. Fig. 162 shows the proportions of the socket capel, which consists of a steel forging. The simplest, and a

most efficient, means of attaching the socket capel to a rope is to pass the rope through the capel, drive a tapered mandril into the core of the rope to form a cone, and draw the rope into position by suspending a load on it. A capel of this form when tested to destruction held till the rope broke. An alternative

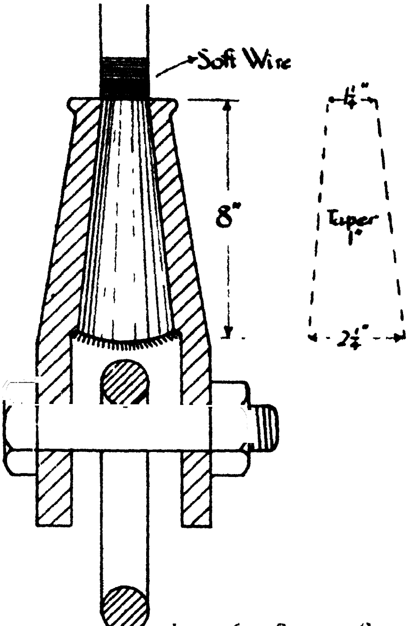


FIG. 162. SOCKET CAPEL

method of making the capping is to open out the wires, cleanse them with petrol and dry them over a coke fire, then coat the wires lightly with powdered resin. The socket is then heated as hot as the hand can bear, then it is drawn back on the prepared wires and filled with molten white metal. It is required by law that the melting point of the white metal should not exceed 570° F., and the pouring temperature 685° F.

Important Statutory Requirements. The Coal Mines Act and subjoined Regulations and Orders should be studied in

relation to winding and haulage, and the following sections are worthy of note—

1. Detaching hooks shall be provided in vertical shafts. (Sect. 40 (2).)

2. Automatic contrivance shall be provided in vertical shafts exceeding 100 yd. in depth to prevent overwinding. (Sect. 40 (2).)

3. Guides shall be provided in every working shaft over 50 yd. in depth, and in every shaft in the course of being sunk over 100 yd. in depth. (Sect. 40 (3).)

4. Keps shall be provided at the surface. (Sect. 40 (4).)

5. Winding ropes shall be recapped at intervals of not more than six months. (Sect. 40 (5).)

6. Cages shall be provided with catches, fenced sides, gates, and rigid bar. (Sect. 40 (7).)

7. Rods shall not be used for attaching cage to winding rope unless through the medium of an efficient spring.

8. Efficient brakes shall be attached to drums used for raising or lowering persons by mechanical power, and a depth indicator shall be provided. (Sect. 40 (10).)

9. When the depth exceeds 25 yd. an efficient system of signalling shall be provided.

10. The capping of a winding rope shall withstand a strain seven times that of the maximum load. (Gen. Reg. 83 (*a*).)

11. The capping of a haulage rope shall have at least 60 per cent of the breaking strain of the rope. (Gen. Reg. 83 (*b*).)

12. Rivets shall not be used in capping a winding rope. (Gen. Reg. 85.)

13. Melting point of white metal shall not exceed 570° F., and the pouring temperature 685 F.

14. When white metal is used wire shall be cleaned and the socket shall be heated to 212° F. (Gen. Reg. 88.)

Use of Detaching Hooks. Where the apparatus ordinarily used for raising or lowering persons to or from the surface is worked by mechanical power it shall, if the shaft is vertical, be provided with a detaching hook. This provision is intended to ensure the safety of persons should the cage in which they

are riding be raised too high above the ordinary banking level. The object of using a detaching hook is to release the rope in the case of an overwind and to suspend the cage in safety. Several forms of detaching hook are in use, but only three are to be described here.

Ormerod's Detaching Hook. Fig. 163 shows the Ormerod hook to consist of three steel plates that are pivoted about a central bolt, through the nut of which a split pin is seen to pass. The rope capel is attached to the upper shackle *A*, and the cage chains are attached to the lower one. When assembled in working order a copper pin keeps the plates locked in such a position that the upper shackle is held firmly in position, but should the hook be raised into the bell in the headgear the lower ends of the outer and central plates *HH* are pressed together, the copper pin is shorn and the upper ends of the plates are pressed outwards, thus releasing the upper shackle. The hook is caught in the bell by the catches formed on the plates, as seen in the third and fourth views, and the cage is thereby suspended. To release the cage again the shackle *A* is attached to the central plate and the hook is lowered down through the bell. The cage is supported on the keps or beams placed across the shaft, and the hook is readjusted to its normal position in readiness for the resumption of winding operations.

Walker's Detaching Hook. This hook consists of two specially formed levers that are pivoted about a central bolt *b*, seen in Fig. 164, and these are normally held in position by a heavy steel collar *c*, through which passes two copper rivets shown at *d*. In this position the shackle attached to the rope capel is held firmly in position, but should the cage be over wound the collar *c* engages with the sides of the bell, the rivets are shorn, and upper ends of the levers are raised through the bell and the rope is released, but in being pressed outwards the catches are forced into the positions in which they catch the upper edge of the bell, so that the cage is held suspended by the hook on the bell. To restore the hook to its normal position the cage is propped up and the hook is taken from

FIG 163 ORMEROD'S DETACHING HOOK

the " bell " formed in the supporting beams, if a metal one is not provided. The hook is reassembled and winding resumed.

Wright's Improved King Hook. Fig. 165 exhibits the main features of this form of detaching hook. It is seen to consist of four plates, the two outer ones being fixed and enclosing the two inner movable ones, which can move about the strong central pin shown under the upper shackle. The copper pin by which the plates are held together in their normal relative positions is shown below the main bolt. The outer plates are of the same width up to the spring of the upper curve, but the inner plates have catches formed on opposite sides, and their lower portions are so formed that when the hook is drawn into the bell the inner plates are pressed in at the bottom, thus shearing the copper pin and pushing the catches outwards to catch the plates on the top and near the bottom of the bell and suspend the cage while the shackle is released. The hook is removed from the bell by using a longer shackle than that ordinarily used, the pin of the shackle being passed through the hole above the central bolt. The bolt passes through all four plates, and so the hook may be raised in the bell and the inner plates pressed inwards to allow the cage and hook to descend. The cage is propped up on the keps, or on beams laid across the cage space at the banking level, and the hook is reassembled in the normal position for winding.

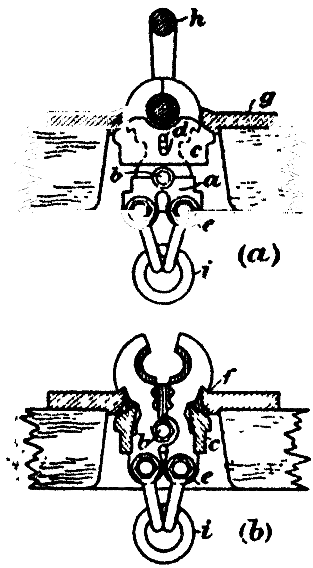


FIG. 164 WALKER'S DETACHING HOOK

Care in Use of Detaching Hooks. Care is necessary in

assembling the several parts of the hook to see that the central bolt is properly fitted and that the nut securing the plates in position cannot work loose, and in fitting the hook together a test should be applied to the copper pin to ensure that normally the pin is not subjected to shear. The plates should

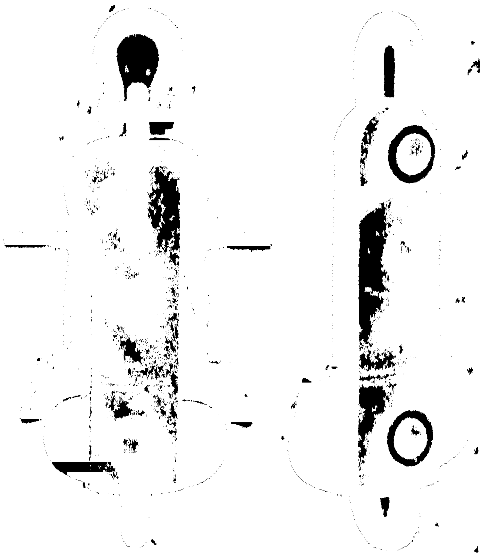


FIG. 165. WRIGHT'S IMPROVED KING HOOK

be examined periodically and, after cleaning, they should be lubricated to ensure their proper action in emergency.

Headgears. Headgears[1] are necessary to enable loaded tubs to be raised to such a height as is required to facilitate the coal-screening operations, and since provision must also be made for the effective use of detaching hooks in the case of overwinds some height must be allowed as a margin in which a

[1] See "Colliery Headgears," by Wardell, in *Colliery Engineering*, March, 1924.

possible overwind might be avoided. If an automatic controller is fitted to the winding engine it might not be necessary to provide such a margin of height as would be provided were no controller installed. Obviously the height of the banking level is also an important factor, for if the banking level is at ground level the headgear might be 20 to 25 ft. lower from

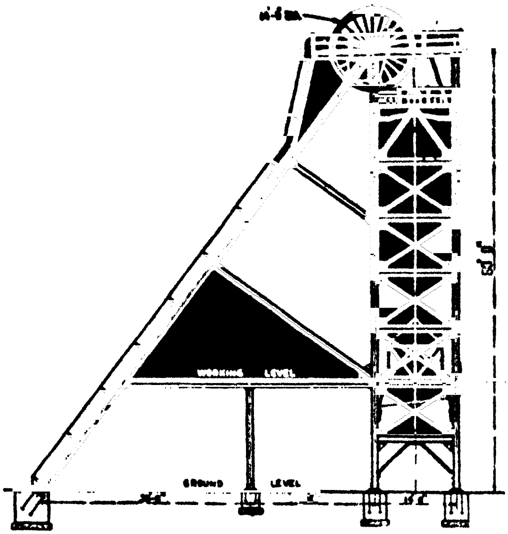


FIG. 166 CHANNEL STEEL HEADGEAR

the ground level to the centre of the pulleys than it would be in the general case. Headgears are made of wood, steel, or reinforced concrete, and there are a great variety of designs whatever the material of construction may be. Fig. 166 shows a channel steel headgear (by Jessop & Co., London) with the main dimensions. Headgear pulleys may be made of cast steel or cast-iron, or they may be constructed with wrought-iron or steel arms and cast boss and rim. The shaft is made of wrought-iron or steel, and the journals are housed in pedestals which provide for siphon or Stauffer lubrication.

Having regard to the inertia of pulleys, it is advisable that they should be made of light but strong materials so that they may be easily set in motion and unlikely to continue to revolve when the wind has been completed. In the latter circumstance the rope might mount the rim and lead to serious accident. If the reader examines a headgear he will be quite likely to find that the feet of the back stays are set back against the front of the winder, and may even be placed on the foundation pillars of the winder. This is done to ensure stability of the frame under the greatest load, and it is easy to see that the back stays of the frame would have to be set farther back if rigid guides were used to guide the cages than if wire guides were used.

Winding Drums. The winding drums commonly used in this country are either cylindrical or cylindro-conical, but there are still in use some of those enormous drums that are much more conical than cylindrical. Cylindrical drums may be made in one or two parts. When the drum is made in one piece the two cheeks and central supporting ring are made of cast-iron and these are keyed to the drum shaft. The brake rim is cast on one of the cheeks and the cylinder is formed by a lagging of oak battens bolted to the cheeks and the central supporting ring. The winding ropes pass by a curved path formed on the cheeks of the drum to the interior, where a length of rope sufficient to allow for recapping is wound on a small drum attached to each drum cheek. The auxiliary drums are loosely fitted to the drum shaft, but are capable of being fixed by bolts passing through them into the main drum cheeks. The drum cheeks may also be built up with straps of wrought-iron attached to octagonal bosses keyed to the shaft. Drums made in this way are lighter and enable economy to be effected in the use of power and in the initial cost of the winder. When it is necessary to raise coal from two different levels in the shaft, two drums of different diameters are attached to the drum shaft. Cylindro-conical drums are designed with the object of securing a balance of load throughout the winding operation, and this is attained by having a combination of a

small cylindrical drum and a larger one with a spiral leading from the one to the other.

Harworth Main Colliery Drum. This drum[1] was designed and made by Messrs. Vickers, Ltd., Barrow. With the exception of the drum cheeks, which are of cast-iron, the drum is built up of steel plates. The large cylindrical portion is 26 ft. diameter over the lagging and 74¾ in. wide between the

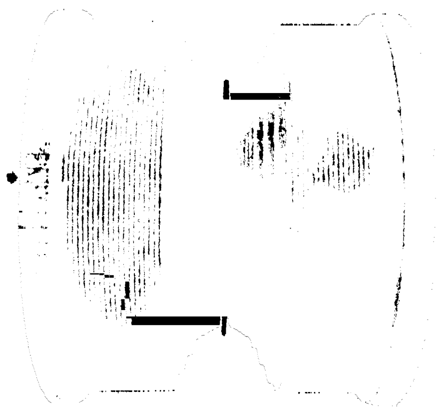


FIG. 167 CYLINDRO-CONICAL DRUM

flanges. It is made in four parts of 1-in. plate, stiffened internally by two pairs of 15-in. by 4-in. channels arranged back to back, and is united to the scroll plates by 6-in. by 6-in. angles. The scroll plates are ¾ in. thick, and each is made in eight sections. These are connected to each other and to the drum cheeks and cylindrical portion of the drum by 8-in. by 8-in. broad flanged beams with two 8-in. by 6-in. beams as intermediate stiffeners in each section. The drum cheeks have eight arms cast integral with the brake paths and the small diameter starting portion. They are made in halves united by two 4-in. bolts and four shrink keys recessed in the bosses

[1] *Colliery Engineering*, Sept., 1924, page 315.

which are 46 in. diameter and 28 in. wide. Scroll iron riveted to the scroll plates carries the rope from the small diameter to the large diameter in 10 turns. Two cast-iron reels are contained within the drum each to hold 300 ft. of rope, and the brake paths on each side of the drum are 16 ft. in diameter and 12 in. wide. Another form of drum of this type is shown in Fig. 167. This drum was specially designed for an electric winder by Messrs. Fraser & Chalmers, Erith, and it is seen that the conical portions are placed in the middle of the drum, and the cylindrical portions at the ends. This combination of the cylindrical and conical drums has been designed to reach a compromise between the efficient and costly drum of the conical type and the less efficient and less costly cylindrical drum. It is lighter and cheaper than the larger conical drum, and provides a conical section sufficient to give the necessary counterbalance at the beginning and end of the wind.

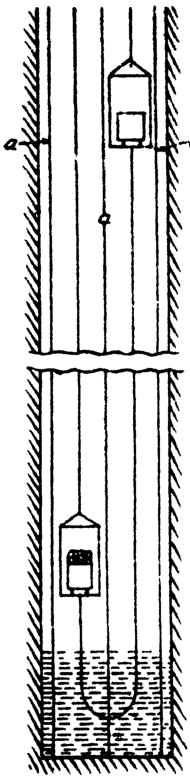
Negative Load. Consider the case in which 4 tons of coal are to be raised in 8 tubs, each weighing 10 cwt., in a cage weighing 6 tons, and that the weight of the winding rope is 8 tons. At the beginning of the winding operation the loads are as follows

Load side		Empty side	
Cage . . .	6 tons	Cage . . .	6 tons
Tubs .	2 ,,	Tubs . . .	2 ,,
Coal . . .	4 ,,	Coal . . .	nil
Rope . . .	8 ,,	Rope . . .	nil
	20 tons		8 tons

This shows a positive balance of 12 tons, but at the end of the operation the loads are as follows—

Load side		Empty side	
Cage . . .	6 tons	Cage . . .	6 tons
Tubs . . .	2 ,,	Tubs . . .	2 ,,
Coal . . .	4 ,,	Coal . . .	nil
Rope . . .	nil	Rope . . .	8 tons
	12 tons		16 tons

This shows that there is a load of 4 tons operating in favour of the winder, for which reason the load is called negative load. It is seen that the negative load arises from the transference of the weight of the rope from the load side to the empty side, and that the amount is the difference between the total weight of rope hanging in the shaft and the weight of coal being raised. It is of interest to note that a static balance might be obtained at three-quarters of the depth of the shaft.



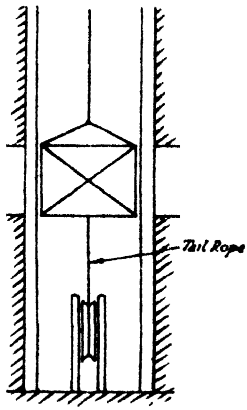


FIG. 168. TAIL-ROPE SYSTEM OF COUNTERBALANCING NEGATIVE LOAD

Counterbalancing Negative Load. The modern methods of counterbalancing negative load are: (1) By the use of a tail-rope. (2) By the use of cylindro-conical drums. (3) By the Koépe system of winding.

Tail-rope System. In this system a tail-rope of the same weight per fathom is attached to the bottom of both cages as

shown in Fig. 168, the rope being allowed to form a natural loop *in the sump or to pass round a pulley in that position.* In raising a loaded cage from the bottom of a shaft the weight of cage, tubs and rope on one side is balanced by the corresponding weight on the other side, and consequently the net load to be dealt with by the winder is that due to the weight of coal being raised, but as the load has to be accelerated from zero velocity to full speed, and that speed is maintained for

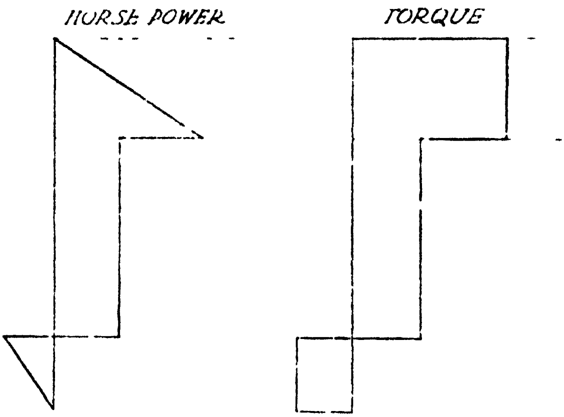


FIG. 169. TORQUE AND HORSE-POWER DIAGRAM

some time, after which the speed is reduced by application of the brake to zero again, it must be apparent that the effort of the engine is a varying one. The variations in torque and horse-power are represented in Fig. 169. During the first period of constant acceleration the torque is constant, and the power increases to a maximum when the speed becomes constant. Since the speed is now uniform for a part of the whole period the torque and power are constant and less than their maximum values during the acceleration of the load and rotating parts of the engine, and when the speed begins to diminish to zero by the application of the brakes the torque and power become negative.

Counterbalancing by Cylindro-conical Drum. When conical

drums were used it was with the view of having uniformity of torque from the beginning of the winding to the end, a condition that may be represented by the following equation—

$$(W + w_r)r - wR = W \times R - (w + w_r)r$$

where W = weight of loaded cage in lb.
w = ,, ,, empty ,, ,,
w_r = ,, ,, rope in lb.
R = maximum radius of drum in feet
r = minimum ,, ,, ,, ,,

Knowing the values of the several loads and the minimum radius of the drum (usually not less than 80 times the radius of the winding rope), it is possible to evaluate R in order that the balance of torque acting against the winder would be uniform.

Example 70. Calculate the maximum radius of a conical drum to deal with the loads set out on page 298; the minimum radius being 7·5 ft.

Solution.

$$(W + w_r)r - wR = WR - (w + w_r)r$$
$$(12 + 8)7{\cdot}5 - 8R = 12R - (8 + 8)7{\cdot}5$$
$$150 - 8R = 12R - 120$$
$$R = 13{\cdot}5 \text{ ft.}$$

There could not be any negative load if a conical drum having these proportions was used to deal with the given loads, but if the drum is made of the cylindro-conical type having several turns of rope on the cylinders of maximum and minimum diameters its width may be less than that of a conical drum having the same rope capacity, and consequently while the torque may not be uniform throughout the winding the drum may be made lighter, which is an advantage from the viewpoint of power consumption. It is clear that the negative load has been counterbalanced.

Koépe System of Winding. An outstanding example of this system of winding is that installed at Plenmeller Colliery,

Haltwhistle. The drive is electrical and the winder is placed on the headgear beside the driving pulley. As is seen in Fig. 170, the winding rope passes from one cage over a headgear pulley, round the driving pulley, and back over the other

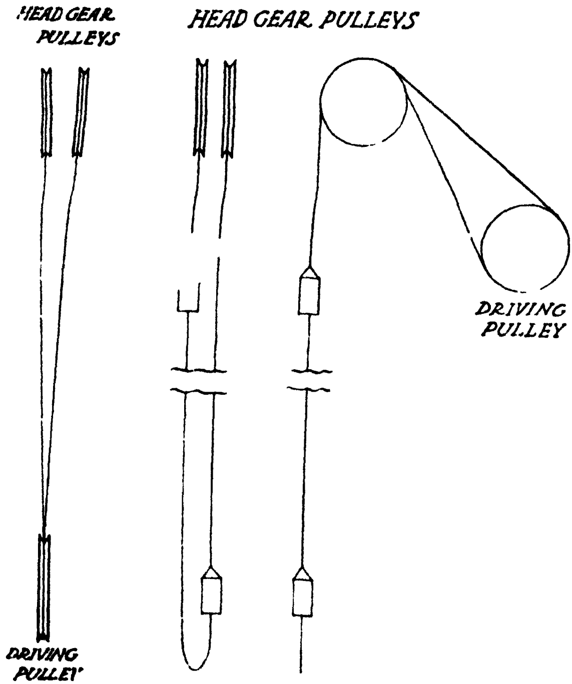


FIG. 170 KOEPE WINDING GEAR

headgear pulley to the other cage. A tail rope is attached to the bottom of the cages and hangs in the sump as a natural loop, being prevented from kinking by passing round a partition or a pulley. The load on the driving pulley is just the weight of coal plus the force necessary to accelerate the load, and since the inertia of the driving pulley is small the power required to put it in motion is also small. It is sometimes said

that the tendency of the rope to slip over the driving pulley is such as to render the system unsatisfactory in working, but it may be shown that while the normal arc of contact between the rope and the pulley is about 180°, the minimum arc necessary is much less. If we suppose that the weight of coal, cage, tubs and rope on the load side is 14·5 tons, and that the weight of coal being raised is 3 tons, the value of the angle θ in the formula $\frac{T_1}{T_2} = E^{\mu\theta}$ may be found. Let $\mu = 0·3$, the co-efficient of friction of steel on the wood lined groove of the driving pulley, then

$$\frac{14·5}{11·5} = 2·718^{0·3\theta}, \text{ and } \log\left(\frac{14·5}{11·5}\right) = 0·3\theta \log 2·718$$

$$\therefore \theta = \frac{0·1004}{0·3 \times 0·4343} = 0·77 \text{ radian or } 44°$$

Load on a Winder. The total load on a winding engine or motor is the difference between the sum of the loads and equivalent loads on the upcoming side and the pull on the downgoing side. The forces operating on the load side of the engine are: (1) Static loads (2) Force required to accelerate load. (3) Friction of cage shoes on guides (4) Forces required to overcome inertia of drum and pulley (5) Bending stresses in winding rope.

The static load at the commencement of the winding is the sum W of the weights of coal, cage, tubs and rope, stated in pounds. The force required to accelerate the load W, based on Newton's second law of motion, is expressed by $P = Ma = \frac{W}{g}a$, where a is the acceleration in ft. per sec. per sec. P is given in pounds. When a load W is moved in contact with the surface of the guides a force F must be applied to overcome the frictional resistance. In the case of cage guides the value of μ may be taken as 0·015, hence $F = W\mu = 0·015W$.

The force which may be said to act at a distance equal to

the radius of gyration from the centre of a drum may be reduced to the radius of the drum, or that part of it upon which is coiling the upcoming rope. The pull on the downgoing rope may be reduced to the same radius by the same method.

Let W_d = weight of drum in lb.

K = radius of gyration of ft.

R = radius of drum in ft.

g = gravitational constant = 32·2

T = force at radius of gyration reduced to radius of the drum on load side in lb.

The equivalent force $T = \frac{W_d K^2}{gR^2}$

The same expression may be applied to the headgear pulley to find the equivalent force required to overcome its inertia.

The load equivalent B of the bending stress of a winding rope is dependent on the flexibility of the rope, and is commonly estimated as varying from 0·3 to 0·5W.

Size of Steam Winding Engine. The simplest form of winding engine is that in which there are two cylinders with their pistons connected by means of connecting rods to the pins in two cranks that are connected to the drum shaft at right angles. Since one of the engines may be on a dead centre at the commencement of the winding cycle, the other should be capable of developing the power necessary to raise the load from rest. In stating the equation of work for the determination of the chief dimensions of the cylinders, the work done during the first revolution is considered to be done in one cylinder, thus—

Work in engine = work done on load

$$\frac{\pi}{4} d^2 \times P \times 2L \times E = \pi D \times \text{net load in lb.}$$

$$\text{and } d^2 = \frac{2D \times \text{net load in lb.}}{PLE}$$

where d = diameter of cylinders in inches

D = ,, ,, drum in ft.

P = effective steam pressure in lb. per sq. in.

L = length of stroke in feet $\left(= \frac{2d}{12} \text{ or } 2{\cdot}5\frac{d}{12}\right)$

E = mechanical efficiency of the engine $\left(= \frac{4}{5}\right)$

Example 71. A pair of coupled winding engines are to be installed to raise a load of 2 tons of coal per wind from a depth of 200 fathoms, the steam pressure being 100 lb. per sq in., and the weight of the parallel drum 20 tons. The diameter of the drum is 14 ft., and its radius of gyration is 5 ft. Find the chief dimensions of the cylinders. Let a = 6 ft. per sec.[2]

Solution. Since the weight of coal being raised is 2 tons, the weight of tubs may be taken as half of that, and the weight of the cage, chains and hook equal to the weight of the loaded tubs, therefore the load = 6 × 2240 = 13,440 lb.

$$C^2 = \frac{13{,}440}{896 - 200} = 20 \text{ lb. per fathom}$$

$$P = \frac{Wa}{g} = \frac{(13440 + 20 \times 200)6}{32{\cdot}2} = 3249 \text{ lb}$$

$$F = 0{\cdot}015W = 0{\cdot}015 \times 17{,}440 = 262 \text{ lb.}$$

$$T = \frac{20 \times 2240 \times 5^2}{32{\cdot}2 \times 7^2} = 710 \text{ lb}$$

$$B = 0{\cdot}4 \times 17{,}440 = 6976 \text{ lb.}$$

The sum of the load and equivalent loads is 28,643 lb., and the weight acting in favour of the engine equals the weight of the cage and the empty tubs, i.e. 4 × 2240 = 8960 lb., therefore the unbalanced load = 19,683 lb.

In finding the diameter of the cylinders we may assume the length of the stroke to be $\frac{2{\cdot}5d}{12}$, hence—

$$d^2 = \frac{2 \times 14 \times 19{,}683 \times 12 \times 5}{100 \times 2{\cdot}5d \times 4}, \text{ and } d^3 = \frac{28 \times 19{,}683 \times 60}{1000}$$

$\therefore$ d = 32 in. and L = 6·66 ft.

Summary.

Diameter of cylinders	. 32 in.
Length of stroke	. 6 ft. 8 in.
Steam pressure	. 100 lb. per sq. in.
Weight of rope	. 20 lb. per fathom
Diameter of drum	. 14 ft.

This example has been given to show that the problem of the winding engine is not really so simple as is indicated by the simple formula, $d = \sqrt{\frac{7 \cdot 5 W}{p}}$, where W is the static unbalanced load, but since the design of a winding engine is the work of a specialist, the ordinary reader need not attempt a more exact solution than that given.

Winding Engines. The duty of a winding engine is to raise coal or rocks from the mine through a vertical shaft, and in addition to lowering and raising the workmen employed underground the engine must be capable of handling such plant or machinery as may have to be sent underground with perfect simplicity and under complete control.

Winding engines are divisible into the following classes—

1. Single-cylinder engines of the non-condensing type.
2. Two-cylinder engines of the non-condensing type.
3. Two-cylinder cross-compound engines using steam expansively.
4. Four-cylinder tandem compound steam engines.
5. Electric winding engines driven by continuous current, or alternating current, or a combination of D.C. and A.C. systems.

Engines of the first class are commonly geared, those of the second class may or may not be geared, but it is usual to have engines of the third and fourth classes directly connected to the cranks or the drum shaft. Electrical winding engines may be geared or they may be directly connected to the drum shaft. Of the various kinds of steam engines, it is most commonly found that the two-cylinder, non-condensing engine is used at collieries, and as the exhaust steam from the winding engine may be discharged into a heat accumulator at a pressure of five or six pounds above atmospheric pressure, it is possible

to generate electric or compressed air power by driving generators with the exhaust steam in low- or mixed-pressure turbines. If it is unnecessary or undesirable to effect economies in this way, compound engines may be installed to take advantage of the expansive properties of the steam. Expert opinion is divided on the question of the economic advantage of electrical winding engines, but there can be no division of opinion on the mechanical advantage of these machines and their reliability has been completely established. Having regard to extent of the subject and the limited space available, we shall concern ourselves mainly with the most common types of steam and electrical winding engines.

Coupled Non-condensing Winding Engines. Winding engines of this type consist of two cylinders that are fitted with pistons which are connected to the cranks on the drum shaft by means of piston rods and connecting rods, the cross-head junction between the latter running in bar or trunk guides. In the case of the smaller sizes of these engines the distribution of steam is effected by means of ordinary *D* slide valves, which are actuated by eccentric sheaves fitted to the drum shaft, the motion being communicated to the valves by eccentric straps, connecting rods, and Stephenson link gear. The reversal of the engine is effected by a hand-lever, the steam is admitted by a stop-valve (throttle-valve), and the brake, which must of necessity be applied direct to the drum, may be actuated by hand-lever or a foot-tramp. At the commencement of a winding the engineman gives a full throttle to the steam, and when the speed has attained the maximum the entry of steam is checked a little to admit of the engine running at full speed for the desired period, and at the completion of that period the steam is cut off at the throttle-valve to admit of the remainder of the operation being completed by the energy of the masses in motion. During this last period it is necessary to apply the brake, and it may be necessary to apply steam to the pistons for the purpose of bringing the engine to rest.

When engines are of large dimensions it is usual to have them fitted with Cornish drop-valve gear, or Corliss gear, with

suitable tripping gear to enable the steam to be used expansively, and, therefore, with economy. The valve-gear may be operated by eccentrics on the drum shaft, by eccentrics attached to the shaft of a drag crank, or by eccentrics attached to a lay shaft running alongside the engines as in Fig. 36. The reversal of such engines is almost invariably effected by an auxiliary steam-engine, and the brakes may be operated either by steam or by a foot-tramp. Such engines must be fitted with a depth indicator and some mechanism which will prevent over-speeding or over-winding, and provision must be made for the transmission of visual as well as audible signals from the onsetter and banksman.

Melling's Patent Steam Reverser. It is an essential feature in a steam reverser that the engine should respond immediately to the action of the winding engineman, and that is a feature which is possessed by the Melling steam reverser. Fig. 171 is a sectional representation of the reverser, and it shows the connections to the reversing lever and the Stephenson link gear. It is seen that the steam cylinder is placed directly above the water cylinder, which is completely submerged in the water contained in the tank in which the apparatus is placed. Piston valves attached to the extension of the rod *G* control the admission and ejection of steam and water from the respective cylinders, and it should be noted that the middle one of the three pipes connected to the steam cylinder is the inlet pipe, the others being exhaust pipes. When the engineman pulls back the handle of the reversing gear the rod *G* and the valve rod *O* are raised, thus admitting steam to the upper side of the piston *A* and allowing water to pass into the lower cylinder *B*, through the port between the valves, to the upper side of the piston. Meanwhile the water on the under side of the piston is ejected through the lower port into the tank. The downward movement of the pistons is accompanied by a similar movement of the rods *G* and *O*, and the steam and water ports are simultaneously closed, thus preventing the admission or ejection of steam or water and holding the reversing gear securely in position. When the reversing

handle is moved forward the direction of motion of the pistons is reversed and the slipper in the Stephenson link is made to

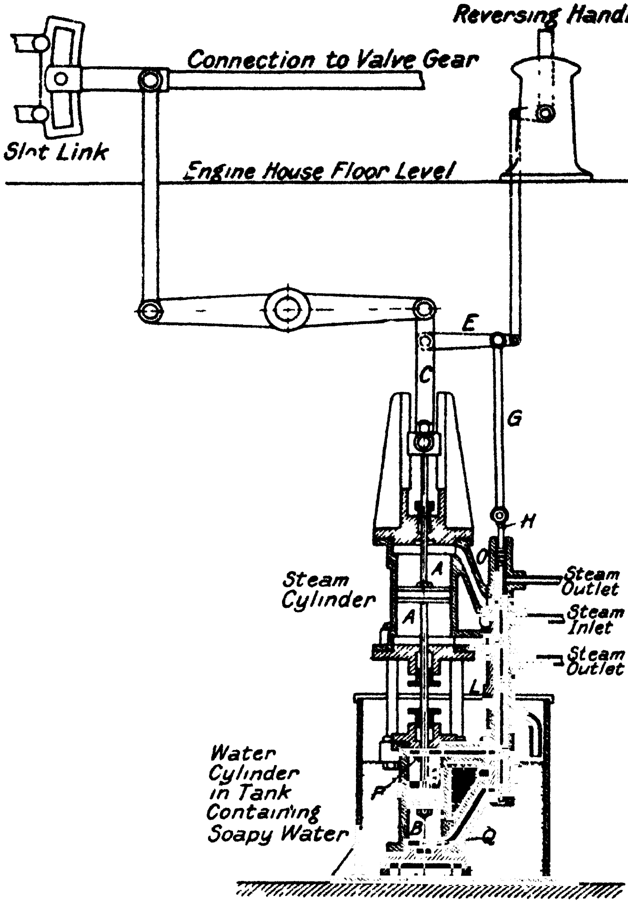


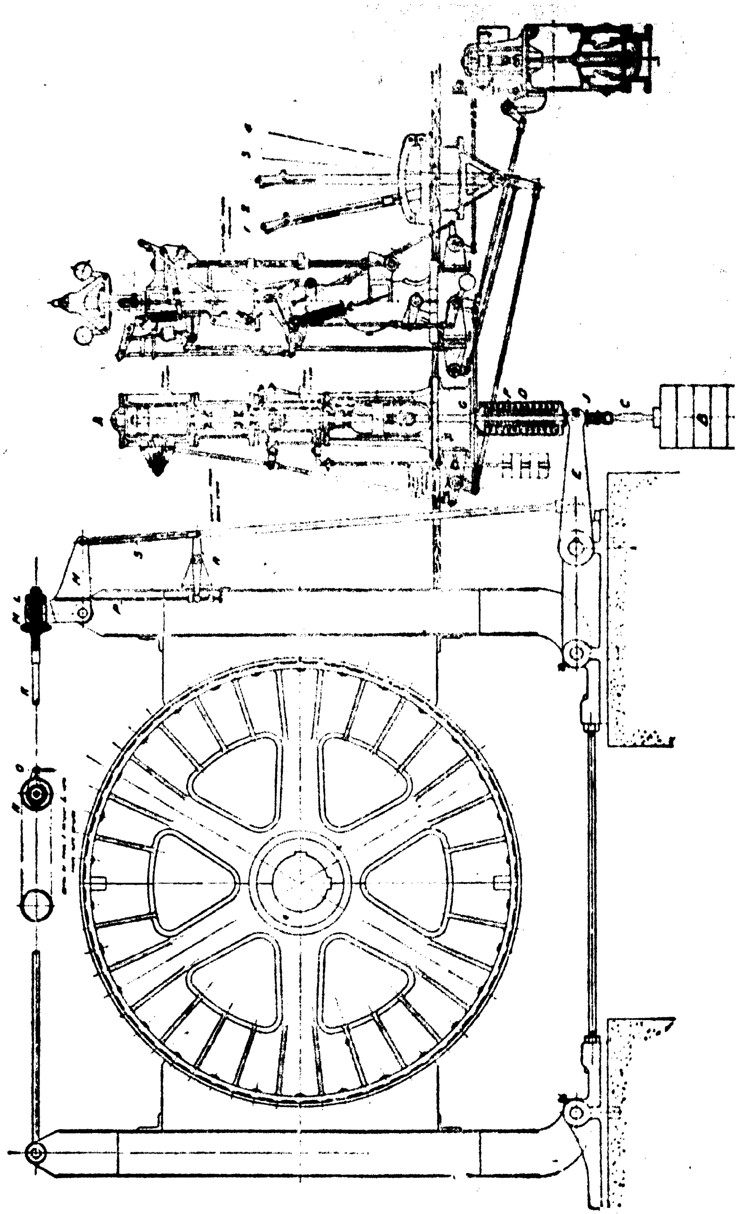
FIG. 171 MELLING'S STEAM REVERSER

pass from the upper position to the lower one, thus moving the steam valves attached to the cylinders of the winding engine into the position required for reversal of the direction of

running. Smooth working is a feature of this device, its action is immediate, and the pistons are securely locked in desired positions. The mechanism should be kept thoroughly lubricated, and it is desirable that the tank should contain soapy water.

The Whitmore Controller and Brake. The brake mechanism for either steam or electric winder must be perfectly reliable and at the same time positively and easily controlled. It must essentially provide that: (1) Any desired brake load can be applied gradually and with certainty between minimum and maximum. (2) The brake load actually applied always corresponds to the same position of the control lever, otherwise it is impossible for the driver to apply any desired braking with certainty. (3) In case of necessity it shall be capable of holding the winder with certainty against full steam or electric torque as the case may be. The brake engine should further be under control of a governor to eliminate entirely the possibility of human error or failure. These conditions are completely fulfilled by the Whitmore controller and brake, made by Messrs. Fraser and Chalmers, Erith. Fig. 172 shows that each drum is fitted with post brakes operating on the specially prepared brake paths of the drum cheeks. A brake engine *A* with cataract cylinder is fitted with floating lever gear by which the positions of the piston correspond exactly to the positions of the brake lever. The wear on the brake blocks is automatically taken up so that for a given brake load the operating lever is always in the same position.

Weights *B* are suspended by rod *C* from the cross-head of the brake engine. These weights put on the brake, while the power applied under the piston raises the weights and takes off the brake. With this arrangement, should any accident occur to the steam or air appliance or brake engine, the brake is automatically applied. It is not usual to provide the weights to hold the drum against the full power pressure, as this is unnecessary, but they are ample to hold the drum against the ordinary winding load, as under the working conditions the full load is applied partly by weight and partly by the power applied on the top of the piston.



Rod *C* is threaded through a spring box *D*, which is free to slide up and down. This spring box bears upon the brake lever *E* and a spring or springs *F* contained in this box are compressed between the bottom of the box and the plate *G*. Brake lever *E* is connected to the top ends of the brake post drawing them together. The varying load is applied by the compression of springs, the weights bringing down with them the top plate *G*, the position of each being controlled by the hand lever. The farther the hand lever goes over, the farther both weights and plate move downwards and so compress the spring more. The general arrangement in Fig. 172 shows the brake with about half-load applied.

The maximum load is applied when the plate *G* is touching the sleeve distance piece in the spring box, and the minimum load is applied when the collar *J* is touching the under side of brake lever *E*, the springs being then fully extended. The position of the hand lever is then at about point 2, and in bringing back this to point 1 the piston travels up still farther, carrying with it the weights and fixed collar *J*; consequently the brake lever *E* moves sufficiently far to give clearance between drum and posts.

At the end of rod *K* there is fitted a ratchet nut *L* mounted in the cross-head *M* of upper brake lever *H*. This ratchet nut *L* has fitted to it a pawl *N* mounted on a lever *O*. The lever *O* is connected by rod *P* to an extended arm of the brake lever *E* and comprises the take-up gear, which acts as follows: On the downward stroke of the brake lever *E* the rod *P* is moved upwards; when the lever and rod *E* are forced down to a certain distance, pawl *N* will take up another tooth; on the return or upward stroke of the lever *E* the rod *P* will be brought downwards by the lever coming in contact with the collar on the bottom of rod *P*, and so screwing up the nut to that extent. The function of the controller, which is shown in front of the starting lever, is to take the control of the winder out of the hands of the driver should he at any time make a slip or fail in his duties. A driver may at any time start a wind in the wrong direction, or fail in regulating the speed of

the wind at the correct time and so finish winding at too great a speed, causing an overwind. It is, therefore, essential to safety working to adopt a mechanical device which is positive prevention against such occurrences.

Applied to steam winders, the overwinding prevention is combined with speed governing gear, and is driven from the drum shaft. It is arranged so that in the event of the cage rising above a pre-determined point without the speed being reduced both the main steam throttles close and the brakes are immediately, though gradually, applied. Should the driver not close his throttle at the given period in the wind, or for any other reason exceed a certain pre-determined maximum speed, the over-winding gear closes the throttle valve and gradually applies the brakes until the engine is pulled up. This is at a point before it reaches the end of the wind.

The same principle is adapted for A.C. electrically-driven winders, the only difference being that the actuating gear operates on the main motor power circuit instead of the steam engine throttles. The over-winder includes a depth indicator and speed governor driven by positive gearing from the main drum shaft.

The "Wigan" Shaft-signalling System. General Regulation 95 requires that in connection with every winding engine the signal shall be both audible and visual. The "Wigan" audible and visual signalling device, made by Heyes & Co., Ltd., Wigan, conforms to the requirements of G. R. 95, and although it is designed to be operated electrically it may be installed as an electro-mechanical apparatus. Fig. 173 shows the *pointer* type of the apparatus, and it will be seen that there are three dials, one for the banksman and one for each of two mouthings in the shaft, with an additional *men* panel that becomes illuminated when the signal 3 is given, showing the word "men" in bold white letters. The indicator consists of a step by step movement which moves the pointer round one space at a time as the signals are given, and a time lag is incorporated to admit of the number of rings being registered by the pointer, provided the interval of time that elapses between the

rings does not exceed two or three seconds. If this period is exceeded two signals corresponding to the rings given before and after the excessive period would be shown successively on the dial. If the signal 1 is given it is heard by the engineman and it is seen by him on the dial of the apparatus used to transmit the signal; if the signal 2 is given the pointer also shows that the signal has been given, but if the signal 3 is given the pointer indicates the number 3 and the word "men" appears in the illuminated panel.

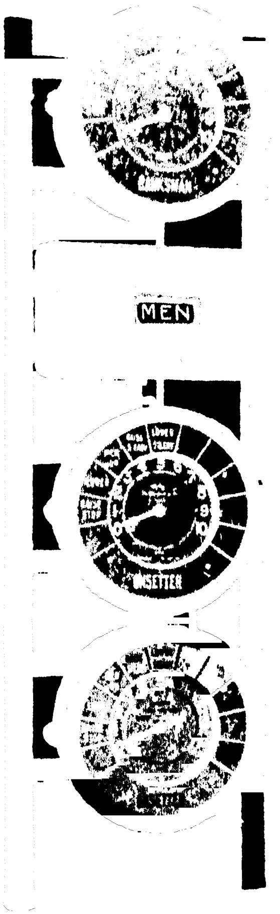


Fig. 173. "Wigan" Signalling Device.

On the cautionary signal 3 being given the indicator pointer will register 3 and the *men* panel will become illuminated. On the action signal 1, 2 or more being given the indicator pointer will return to zero and register the number given, the *men* panel still remaining illuminated. When the engineman commences to carry out the order the indicator pointer will return to the zero position; after he has partly carried out the order, say about one-quarter or one-third of the wind, the *men* panel will be extinguished. The engineman has, therefore, before his notice the word "men" during the necessary decking operations and while men are entering the cage, and also, further, until he has partly carried out the wind. If during the time the cages are running in the shaft

the cautionary signal 3 is given, the indicator pointer will register 3, and when the cages come to rest the pointer will return to zero and the *men* panel will become illuminated, and will so remain during any subsequent decking operations until the wind proper has commenced again

If the signal 1 is given to stop when the cages are running in the shaft the pointer will register 1, but the moment the signal is complied with by stopping the engine the signal is cancelled and a clear dial is shown The whole of the apparatus used to operate the pointer is attached to the back of the dial it is, therefore accessible without cessation of its use Signals are cancelled mechanically by a belt passing round the drum shaft

Electric Winders. The drums of winding engines may be operated by the direct use of A C motors which may or may not be effected by gearing they may be operated by D C motors fed direct from the power mains, or they may be operated by D C motors supplied with D C by dynamos driven by A C motors supplied with A C direct from alternating current mains The first and third systems are used for dealing with comparatively large outputs whereas the second method is used for operating small winders

In the first case the operation of the electric winder is controlled by an oil immersed make-and-break switch in the stator circuit and a liquid controller in the rotor circuit The oil immersed stator switch must be capable of making and breaking on heavy current without undue wear, for a winding motor may be started and stopped once or twice a minute It consists of two separate three-pole oil immersed quick break switches, mechanically interlocked so that only one switch can be closed at a time The rotor switch may be provided with a moving electrode or a fixed electrode The former is used for controlling machines of medium size and the latter for larger machines In the latter case the level of the liquid in the tank and therefore the resistance is altered by means of a centrifugal pump

The ordinary system of rheostatic control is used in the

second case, but in the third case the Ward-Leonard system of control is usually adopted for the reasons that it is suitable for the adoption of safety devices, is convenient in application, and economical in operation. For detailed information readers should refer to Dr. Penman's articles in the *Mining Educator*, and to other articles mentioned at the end of this chapter.

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"The Summerlee Visual Indicator," by Mr D. M. Mowat, vol lii, page 296.

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"The Adjustment of Ropes on Bi-cylindro-conical Drums," by Dr. Parker, vol. lxxi, page 47.

"Control Systems for Electric Winders," by Mr. C. H. S. Tupholme, in the *Colliery Guardian* from 3rd June to 5th August, 1927.

EXERCISE QUESTIONS

1. Sketch and describe a good capel for a wire winding rope about 1¼ in. in diameter, and also the fitting of the capel to the rope (*2nd Class Exam.*, May, 1931.)

2. Beginning at the wire winding rope and ending at the cage, describe briefly the apparatus and attachments that are found in a winding plant. State the materials to be used for the various items. (*2nd Class Exam.*, Nov., 1931.)

3. In connection with the cylinder of a steam winding engine, what are the devices adopted and materials used: (*a*) to prevent steam from passing the piston and the cylinder wall; (*b*) to prevent steam from escaping round the piston rod where it passes through the cylinder cover, (*c*) to make steam-tight joints between the cylinder and the end covers? (*2nd Class Exam.*, May, 1932.)

4. The capel, or socket, at the end of a winding rope is fitted with a pin 1½ in in diameter. The six bridle chains of the cage finish in links 4 in long and 2 in wide (inside dimensions). Make a drawing of the parts wanted for connecting the capel to the bridle chains. Show dimensions and state the kind of materials that you would use (*2nd Class Exam.*, May, 1932.)

5 Describe a good form of capping or socket for a steel winding rope, and also the operation of recapping the rope (*2nd Class Exam.*, Nov, 1933.)

6 The winding engine at a colliery has two steam cylinders, and the drum is on the crankshaft. Give a list of the parts that need lubrication and state how each part may be lubricated. If a bearing is inclined to run hot, what can be done to improve matters while keeping the engine in service? (*2nd Class Exam*, Nov., 1935.)

7. Describe and sketch a set of bridle chains and attachments for a cage whose top hoop is about 10 ft. long and 3 ft. 3 in. wide. The cage weighs with tubs and coal about 5 tons gross. (*2nd Class Exam.*, May, 1936.)

8. Describe a good capel for a steel winding rope, say 1¼ in. in diameter, and the operation of capping the rope. (*2nd Class Exam.*, Nov., 1937.)

9 For guiding cages in a shaft the following may be used: wood guides, steel rail guides, and flexible steel conductors. How may these various guides be arranged and secured in the shaft? Mention conditions for which each type is suited. (*2nd Class Exam.*, May, 1938.)

10. Write a short essay on steel wire winding ropes, dealing with their construction, installation, and treatment in use. Note especially points connected with safety. (*1st Class Exam.*, Nov., 1931.)

11. Describe a good arrangement of brakes and brake-operating gear for a winding engine for shaft, say, 500 yd. deep, where the loaded cage weighs about 5 tons gross and the empty cage about 2 tons. What would be the most severe duty to be performed by the brakes? (*1st Class Exam.*, May, 1933.)

12. Describe an apparatus for attachment to a winding engine for preventing overwinds. State also how it works, how it controls the speed of the cage, and how it brings the engines to rest when the upcoming cage would go too far.

(*1st Class Exam.*, Nov., 1933.)

13. Give a list of typical wire rope constructions and describe them briefly. Indicate the particular purposes for which each construction is most suitable. (*1st Class Exam.*, Nov., 1933.)

14. The length of steel wire winding ropes changes due to stretch and to cutting when recapping, making it necessary to adjust the cage positions. Describe methods of doing this.

(*1st Class Exam.*, May, 1934.)

15. Describe the construction of a three-deck cage and chains to carry men or six tubs, each to hold 10 cwt. of coal. Give the chief dimensions and state the materials used. An outline drawing of the whole cage and chains or a detail drawing of a part should be included. (*1st Class Exam.*, Nov., 1934.)

16. Describe the apparatus you would expect to find in a winding-engine house, apart from the engine proper, at a shaft about 300 yd. deep. (*1st Class Exam.*, May, 1935.)

17. Describe a detaching hook to be placed between the rope and the cage of a winding plant. Show by simple sketches the action of the detaching hook. (*1st Class Exam.*, May, 1936.)

18. Mention and briefly describe the apparatus that may be applied to a steam winding engine for ensuring the safety of the people travelling in the shaft. Is a ball governor in the steam supply pipe to a winding engine of any service? Give reasons for your answer. (*1st Class Exam.*, May, 1937.)

19. You are called upon to examine thoroughly a steam winding plant within the engine-house to see whether it is efficient and in safe working order. To what matters would you direct attention and what would you do? (*1st Class Exam.*, May, 1938.)

20. Enumerate and discuss briefly the measures taken to ensure safety in a steam winding plant at a colliery.

(*1st Class Exam.*, Nov., 1938.)

21. How do you calculate the size of the two cylinders of a steam winding engine? Take the case of a shaft with a wind of 300 yd., with two cages weighing, with loaded tubs, 3 tons and, with unloaded tubs, 2 tons, and drum 10 ft. in diameter on the crankshaft.

The steam pressure at stop valve is 90 lb per sq. in. and the winding ropes weigh 3 lb. per ft.

(*1st Class Exam.*, May, 1939.)

22. Describe one form of visual signalling for a winding engine. In selecting visual signalling apparatus, to what features would you have regard? (*2nd Class Exam.*, May, 1919.)

23. Describe and sketch suitable kep gear for a single-deck cage 5 ft long and 4 ft wide (*2nd Class Exam.*, May, 1922.)

24. A vertical leg of a headgear is a steel joist 12 in by 6 in. in section. Design a base for this leg suitable for resting on, and being secured to, a pier of brickwork or of concrete. Show all important dimensions and details of the design.

(*1st Class Exam.*, Nov., 1926.)

CHAPTER XIII

MINE DRAINAGE

Occurrence of Water in Mines. The water which falls as rain upon the surface of the earth can be regarded as being divided into three portions, viz.: (1) that which is evaporated at the surface of the earth; (2) the portion which is absorbed by the soil and subsoil, and is ultimately carried by the surface drainage to the sea; (3) that portion which passes from the subsoil to the solid rock underneath, and eventually finds its way into such excavations as may be formed during the progress of the development of mines. It is the last portion that is of special interest to those who are engaged in mining operations, irrespective of whether the object of the working is the winning of coal, stone, or metallic ores.

Drainage Methods. Several methods are available for dealing with the water that is encountered in mines, and while it may in general be stated that the method to be adopted is that which involves the smallest charge on the undertaking, there are occasions on which it may be absolutely necessary that economic considerations should rank as of secondary importance to the executive measures dictated by special circumstances. The following systems of mine drainage are employed according to circumstances--

1. Drainage by adit levels.
2. Raising water in water-chests from dip workings.
3. Raising water in water-chests from vertical shafts.
4. Winding water by means of barrels in vertical shafts.
5. Removing water by means of siphons.
6. Raising water by means of pumps of different kinds.

Drainage by Adit Levels. It is always desirable that advantage should be taken of natural conditions to expedite or simplify the drainage of mines. Because of the fact that most of the mines of this country lie at a lower level than the general

level of the country, it is only on rare occasions that it is possible to use this system of drainage. It will be readily understood that the system is more applicable to hilly or mountainous districts where the mine workings are situated mostly, or wholly, above the level of the base of the surface drainage system, than it is to mines that are reached by vertical shafts sunk from the surface on the sides of the valleys. Even in the latter case, however, it may sometimes be possible to lighten the duty of a pump by arranging that the water delivered by it should be discharged into an adit connecting the shaft at some point beneath the surface with a stream running along the base of an adjacent valley.

Use of a Water-barrel. The amount of water encountered in the process of sinking shafts bears directly on the question of which method of raising the water should be adopted. The usual practice in this connection is indicated by the following excerpt from the specification of the conditions of contract for sinking certain shafts: "When the quantity of water reaches eight ordinary sinking barrelfuls per hour, the company shall fit up pumps and the contractor shall take charge of same." Fig 174 shows the usual form of a barrel suitable for winding water It is made of iron throughout, about 3 ft. 6 in. deep and 2 ft. 6 in. diameter across the middles, and 2 ft. 3 in. diameter at the top and bottom. The barrel is suspended by a bow, or hoop *a*, attached to trunnions *b* riveted to the side of the barrel. There is a circular iron valve *c* with india-rubber or leather seating fitted to the bottom of the barrel. Flap-valves may be employed, but it is much better to have the circular valve with a guided spindle *d*. The hoop is kept in position by means of pins *e* and links *f*. When the barrel is lowered into the sump in the bottom of the pit, the upward pressure of the water opens the valves and the water flows in to fill the barrel. The valve then closes, and the barrel is raised to the surface. When the barrel arrives at the surface a trough made of wood and lined with sheet-iron is pushed under it to cover the shaft and to form a channel by which the water is guided to the ditch near the side of the

shaft. The barrel is then lowered sufficiently to allow of a pin attached to the trough in a vertical position pushing the valve upwards and allowing the water to run out. As soon as all the water has run out, the barrel is raised to allow the

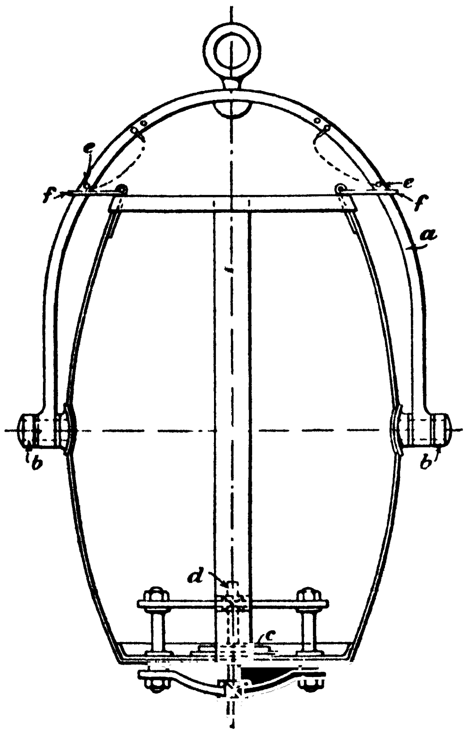


FIG. 174. WATER BARREL.

trough to be withdrawn, and then it is lowered to be filled again. It should be observed that when such a barrel is used in the ordinary course of sinking a shaft it may be, and usually is, necessary to fill it by hand baling.

Galloway's Vacuum Water Barrel. The chief objection to the ordinary form of barrel is that it can be filled only by immersion to the level of the water in the sump. It was this

disadvantage of the simple barrel that led Prof. Galloway to design the vacuum water barrel which was first used at the sinking of the Llanbradach shafts in the early nineties. Fig. 175 is a section of the barrel. In its original form it consisted of a

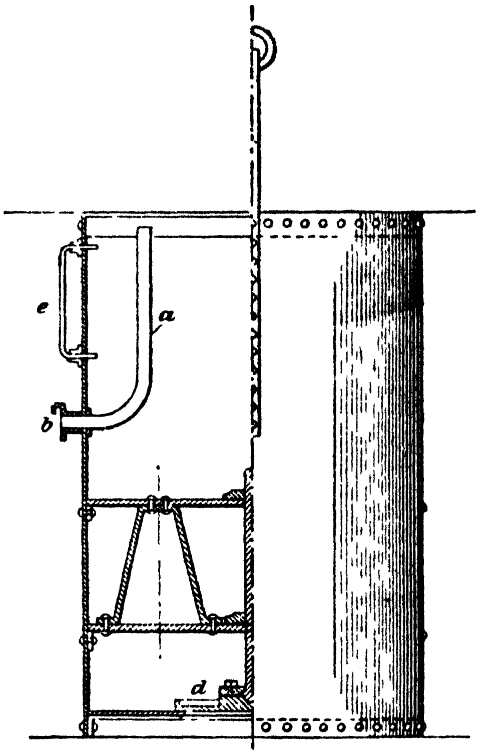


FIG. 175 GALLOWAY'S VACUUM BARREL

cylinder closed at both ends and having a valve opening inwards at the bottom An open pipe *a* with one-half of an instantaneous coupling *b* attached to its outer end, passes through the cylinder at a convenient height above its bottom, and reaches to within half an inch or so of its top. A water gauge *e* is fitted to the cylinder near the top to indicate the

height of water, and thus show when the barrel is full. The barrel is fitted with a hoop by which it is attached to the winding rope. A necessary part of the equipment is a receiver and air pump, which are connected to the barrel by means of wrought-iron pipes cramped to the side of the shaft, and terminating in a piece of flexible hose having the other half of an instantaneous coupling attached to it. A stopcock is fitted to the metallic pipe at its lower end. When the air pump is working a vacuum is produced in the receiver and the pipe leading to the bottom of the pit. Prof. Galloway himself described the operation of winding water by this method as follows: "The water barrel having been set down in the bottom with its lower end resting in the water, the flexible hose is coupled to the pipe leading to its interior and ascending to the top as has been explained. The stopcock is then opened, a vacuum is produced in the interior of the barrel, and the water, forcing the valve *d* upwards, rushes into it. The sinker who has charge of the flexible hose keeps his eye on the gauge glass *e* at the top of the barrel, and when he sees that the water has risen to within an inch or so of the top, he shuts the stopcock, detaches the flexible hose, and then signals for the barrel to be drawn up. The rate at which the barrel can be filled depends partly upon the size of the pipes, extending from the reservoir to the bottom of the shaft through the side of the cylinder to its interior, partly on the diameter of the valve in the bottom of the barrel. At Llanbradach the vacuum pipe was 3 in. in diameter, and the opening in the bottom of the barrel 18 in. in diameter. With these dimensions, a barrel having a capacity of 600 gal. was filled in 30 sec. at a depth of 250 yd. from the surface, but when the depth amounted to over 500 yd. it took 40 or 45 sec. to fill. At the surface the barrel was lowered into a water trolley with a conical block of wood fixed in its bottom, which opened the valve and allowed the water to run out in 30 sec." The barrel may be raised and lowered by the same engine as is used in winding the debris, but if a special engine is set aside for the work of winding water more water may be dealt with,

and according to Prof. Galloway, in his *Lectures on Mining*, the barrel can readily deal with 18,000 to 20,000 gal. of water per hour without interrupting the sinking. An obvious advantage of the vacuum barrel is that it need not be submerged to be filled, and, consequently, the depth of water in a sinking pit need not be greater than is necessary to cover the valve in the bottom of the barrel.

The Self-filling Water Barrel. The self-filling barrel was used in its original form at the sinking of the shafts of the Windsor Colliery, near Caerphilly, in the late nineties. It was designed by a workman named Pearce to take advantage of the important principle of physics, viz.: "The atmosphere acting on the free surface of water in a well sustains, as in a vacuum, a column of water whose height is given by the quotient of the atmospheric pressure in pounds per square in. by the weight of a column of water 1 ft. high and having a base or section of 1 sq. in." One cubic foot of water weighs 62·5 lb., therefore a column of water 1 ft. high and 1 sq. in. in section weighs and will exert a pressure of $62{\cdot}5 \div 144 = 0{\cdot}434$ lb. When the atmospheric pressure amounts to 14·7 lb. per sq. in., the maximum height of a column of water which it will sustain in a vacuum $= 14{\cdot}7 \div 0{\cdot}434 = 33{\cdot}9$ ft. It will be understood from the description that follows that the principle of the self-filling water barrel is precisely the same as that upon which the action of a reciprocating pump is based. Fig. 176 is a sectional elevation of the modern form of the barrel. The barrel consists of a steel cylinder *A*, which is fitted with a turned piston *B*, and has a valve *C* in the bottom. It is caught up by four chains which are attached to the winding rope shackle, and is provided at the top with a guide plate *D* through which the piston rod passes. The piston consists of a circular disc to which the piston rod is attached; it is fitted with an angle-iron ring *E* having the outer surface turned to enable a water-tight joint to be made with the side of the cylinder, and it has four india-rubber valves *F* fitted to the disc. These valves open upwards to allow air under the piston to escape during the downward stroke of the piston. The valve *C* is also made of

india-rubber and is mounted upon a spindle whose vertical movement is controlled by the guide-bars attached to the bottom of the barrel. The barrel is provided with a perforated

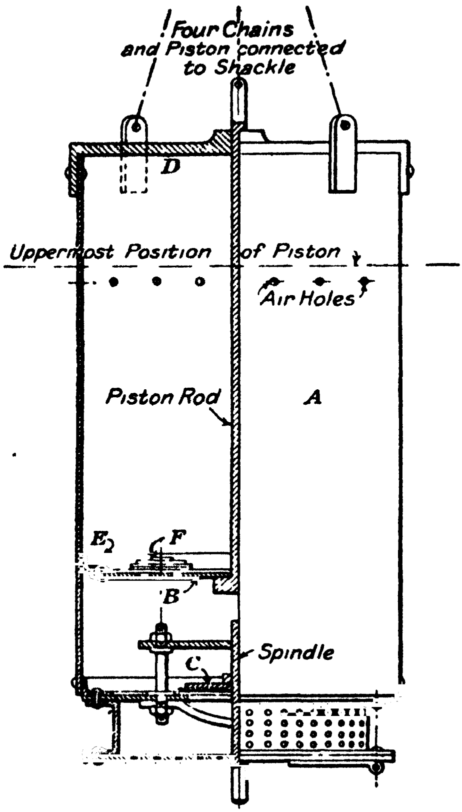


FIG 176 SELF FILLING BARREL

false bottom to prevent the main valve from being fouled by debris, and a hinged door is also provided to enable the valve to be cleaned should it become necessary to do so. When the barrel is lowered to the bottom of the shaft the piston with its valves open descends to the bottom of the cylinder. On raising

the piston the valves *F* are closed and the main valve *C* is opened by the water, which rushes into the barrel until the air-holes in the cylinder immediately under the uppermost position of the piston are exposed. When the barrel reaches the surface a trough is pushed underneath it, and when the barrel is set down on the bottom of the trough the valve *C* is opened, and the water runs out. By means of such a barrel as this the bottom of a sinking pit may be kept practically dry.

Principle and Use of the Siphon. The siphon is a device which finds a wide field of usefulness in coal mines, being employed for conveying water from a point on one level to another at a lower level, over an intervening ridge whose height above the surface of the water in the lodgment at the higher level does not exceed the limit imposed by the intensity of the atmospheric pressure at the higher level, and the frictional resistance of the pipe forming the siphon The height of the water barometer at mean sea-level is normally 34 ft.; this is the greatest possible height of the ridge over which the siphon can convey water from a higher level to a lower one. In practice, the vertical height from the surface of the water at the inlet to the siphon to the top of the ridge, or the crown of the siphon, is less than the theoretical maximum height, depending on the length of the pipe and roughness of its inner surface, for both of these factors influence the amount of resistance opposed to the flow of water. Other factors which influence the maximum height of the ridge over which a siphon will efficiently convey water are the temperature of the water and the amount of gas contained in the water. The former is generally an unimportant factor in coal mines, but the latter is always important, especially in the case of a siphon in which there are abrupt bends near the crown of the siphon. Fig. 177 represents the conditions under which a siphon may be put to work in a mine, and it may be used to elucidate an elementary statement of the principle of the action of the siphon. The essential condition that must exist in order that the water may flow through the siphon from *a* to *c* is that there should not be equilibrium of the force tending to produce and that

tending to oppose the flow of water. The forces which tend to produce flow of water from *a* to *c* are, firstly, the pressure of the atmosphere on the surface of the water in the lodgment at *a*, and, secondly, the head h_2 of water in the discharge limb extending from *b* to *c*. The forces opposing the flow of water are the atmospheric pressure acting on the surface of the water at *c*, and the head h_1 of water in the inlet limb extending from *a* to *b*. The condition of equilibrium may be represented

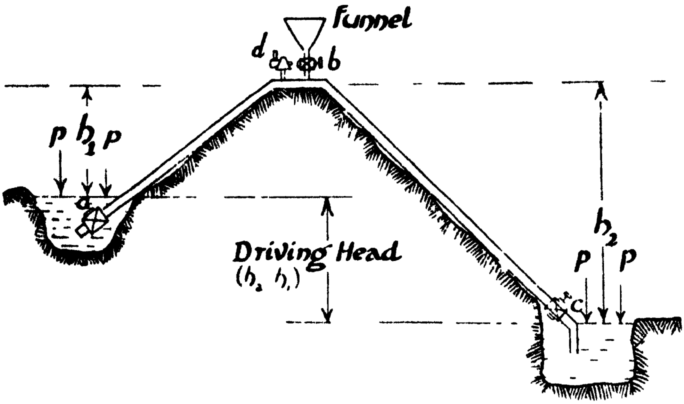


FIG. 177 SIPHON

symbolically by the expression $p + h_2 = p + h_1$ when h_1 equals h_2. If h_1 does not exceed the maximum permissible height, and h_2 exceeds h_1, water will flow, providing the driving head $(h_2 - h_1)$ is sufficient to overcome the frictional resistance of the pipes

Construction of Siphon. The general practice in siphon construction is to use malleable iron or steel pipes with screwed joints, adjacent lengths of pipe being connected by a thimble which brings the ends of the pipes together to form a flush joint. If the ends of the pipes are smeared with red lead before being screwed into the connecting thimble, the joint should remain water-tight and air-tight for a long time. Larger pipes may be connected by bolted flanges, between which rubber rings are inserted to form air-tight joints.

Should any trouble be anticipated from a heaving floor it may be found desirable to install pipes having loose-flanged joints. It is essential that the siphon should be fitted with at least three valves. Fig. 177 shows a check or non-return valve at *a*, the inlet end, an air valve at *b*, and an adjustable valve at *c*, the other end. Practical experience dictates that the valve at *a* should be a non-return one, so that its action will be automatic, and therefore avoid the necessity for any person going into the water to effect its adjustment. The valve *b* may serve the dual purpose of allowing the air to blow off as the siphon is filled, and admitting the water used to prime the siphon prior to its being put into operation. If a pump is used to prime the siphon, a simple snifter cock may be used as an air valve. The valve at *c* is necessarily an adjustable one, for it is usually necessary to regulate the flow of water through the siphon with the object of making its actions continuous.

Hints on Filling the Siphon. Several methods are available for filling siphon pipes, the method used in a particular case being dependent on the conveniences already in existence at the time of the installation of the siphon, and on the amount of water required to fill the pipes. In such a case as that represented in Fig. 177, it is usual to attach a snifter cock to the crown of the siphon close to the funnel. The valve at *c* is closed, both the snifter cock *d* and the funnel valves are opened, and the water is poured into the funnel until the pipes are completely filled as indicated by the water issuing from the snifter cock. Both of the valves on the crown of the siphon are now closed, and when the adjustable valve at *c* is opened water will commence to pass through the siphon, provided air has been excluded from the apparatus and the conditions with regard to the relative heights of *a*, *b*, and *c* and the length of the siphon pipe are not such as to produce cavitation

Calculation of Discharge from Siphon. Where the above condition has been established, the discharge may be obtained by use of the formula—

$$G = 2{\cdot}83d^2 \sqrt{\frac{dh_2}{fl_2}}$$

where G represents flow of water in gallons per minute, d the diameter of pipe in inches, h the unbalanced head in feet, l the length of the pipe in feet, and f a constant.

Example 72. A 4-in. siphon pipe is 1000 ft. long, and the difference in level between the free surfaces of the water at the inlet and discharge ends is 36 ft. Take the value of f to be 0·01, and find the discharge of the siphon.

Solution. $G = 2{\cdot}83 \times 4^2 \sqrt{\dfrac{4 \times 36}{0{\cdot}01 \times 1000}}$

$$= \frac{2{\cdot}83 \times 16 \times 12}{\sqrt{10}}$$

$= 172$ gal. per min.

Strength and Frictional Resistance of Pipes. Pipes intended for the conveyance of water under pressure in and about mines

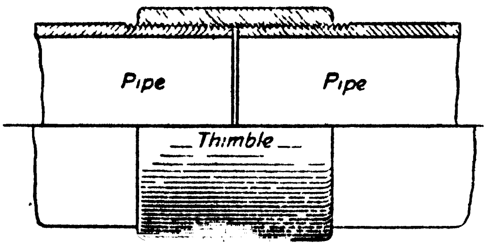


FIG. 178 JOINT IN M I PIPE

are generally made of cast-iron or wrought-iron, the flanges of cast-iron pipes being fixed and cast in a single piece with the body of the pipe; in a country where there is an abundance of suitable timber, wooden pipes may be constructed; and where timber is difficult to obtain and the hydrostatic pressure on the pipe is not excessive, reinforced concrete may be used Fig. 178 shows the form of a joint in malleable-iron pipes of small diameter; Fig. 117 shows one of many forms of loose-flanged joints used in connecting malleable-iron or steel pipes of larger diameter; and Fig. 179 shows a method of making joints in cast-iron pipes. When joints have to be packed it is desirable that the ends of the pipes

should be formed so that the act of tightening up the bolts has the effect of compressing more tightly the jointing material. Figs 117 and 179 are both of the well-known spigot-and-faucet type When the pipes are to be laid in a straight line the jointing material is made in cylindrical form, but should it be desired to lay the pipes down to conform to a curve, tapered joint pieces are used The joint rings may be made of thick sheet iron covered with coarse flannel and dipped in

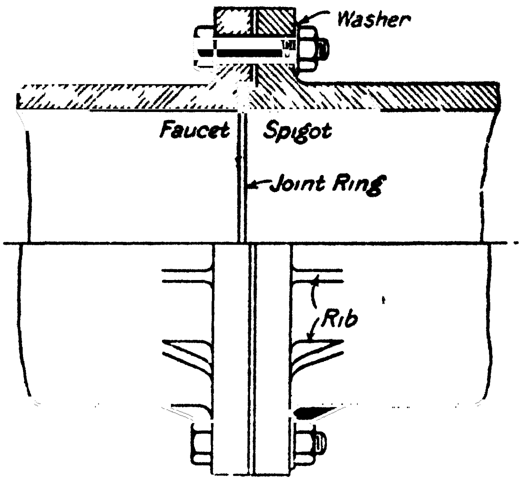


FIG 179 JOINT IN C I PIPE

Archangel tar, or they may consist of rubber which has been reinforced with cord to give greater strength to the rubber.

Loss of Head in Pipes. Pipes conveying water in mines are usually abnormally rough because of the incrustation arising from the deposition of mineral matter, or the roughness produced by the corrosive effect of pit-water having acid properties. The loss of head due to friction is a matter of greater moment with small pipes than with larger ones. The loss of head may be calculated by D'Arcy's formula, viz :

$$h = c\left\{1 + \frac{1}{12d}\right\} \times \frac{4lv^2}{2gd}$$

Example 73. Find the loss of head by friction in an incrusted pipe 2000 ft. long and 6 in. in diameter, the velocity of the water passing in the pipe being 5 ft per sec.

Solution. By D'Arcy's formula,

$$h = 0{\cdot}01\left\{1 + \frac{1}{12 \times 0{\cdot}5}\right\} \times \frac{4 \times 2000}{0{\cdot}5} \times \frac{5^2}{64{\cdot}6}$$

$$= \frac{0{\cdot}01 \times 1{\cdot}1666 \times 4 \times 2000 \times 25}{32{\cdot}2} = 72{\cdot}4 \text{ ft. } Ans.$$

Direct-acting Pumps and Engines. The outstanding feature of the direct-acting pumps and engines is that the steam cylinder or compressed-air cylinder and the pump are in one straight line, and the piston rod is coupled directly to the pump rod. Direct-acting pumps and engines are essentially non-rotative. Such an arrangement may consist of a single ram or plunger pump with a single engine, or it may consist of two pumps placed side by side and driven by two engines that are also placed side by side. Advantage is taken of the latter arrangement to obtain the duplex action of the engines, whether these are simple and non-condensing or compound and condensing. Such pumps are simple in their construction, and by reason of the fact that they do not occupy such a large space as pumps of the same capacity being driven by engines having rotating parts, they are eminently suitable for use underground in positions adjacent to the shaft. The use of steam should be confined to the neighbourhood of the shafts for two important reasons; firstly, because of the risk of fire due to the heat radiated from the pipes; and, secondly, because of the loss of power by condensation in conveying steam to great distances underground. Whereas the exhaust of air-driven engines may have a beneficial cooling effect on the air into which the power-air is exhausted, the steam exhausted from a steam-driven engine not only increases the temperature of the surrounding air, but greatly adds to its humidity, thus creating an unhealthy condition, especially when that condition is accompanied by high temperature. If due attention is given to the proper condensation of the exhaust steam, and care is taken to avoid leakage of steam at

improperly packed joints, the system is capable of giving entirely satisfactory results.

Tangye's "Special" Steam Pump. This pump is made in various sizes to deal with various quantities of water against heads of 600 ft and more. It is fitted with cast-iron piston and rings in the steam cylinder, and cast-iron "bucket" with

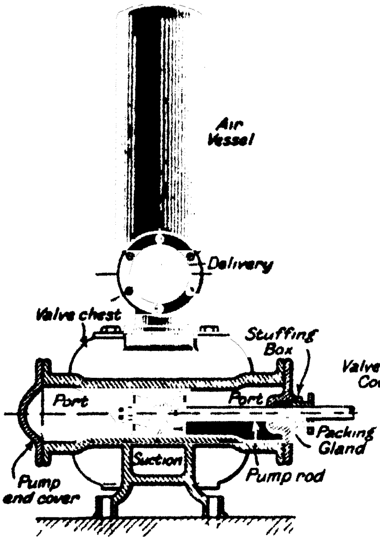


FIG 180 TANGYE PUMP

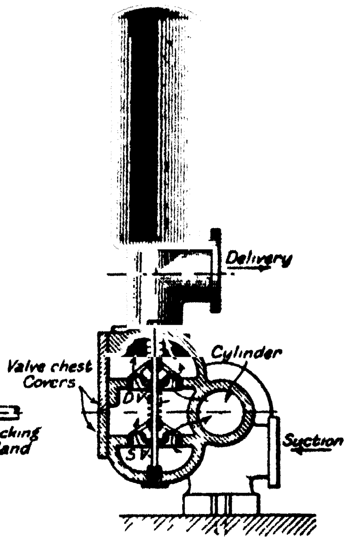


FIG 181 TANGYE PUMP

leather packing in the water cylinder The piston rod is made of steel to withstand the rapidly changing compression and tensile stresses in it, and the valves and valve-seats are usually made of brass. Fig. 180 is a longitudinal section of this pump, and it shows the suction pipe to be attached to the pump on the opposite side from the valve chest. The delivery outlet is shown branching from the base of the air-vessel over the body of the pump, but that is a matter which is entirely dependent on local conditions. The figure shows several parts of the ram, with the leather packing pieces appearing conspicuously in the section. Fig. 181 shows the pump in

cross-section, and exhibits the arrangement of the valves on a common spindle which is fitted to top and bottom of the valve chest. It is seen that the valve, having concentric seatings, admits the flow of water outwards as well as towards the spindle, and as the closure of the valves is effected by the helicoidal springs above them, slip is reduced to a minimum. When the ram makes a stroke towards the right, water flows in through the suction valve, and by the left-hand port into the cylinder. When the stroke is reversed, the water in the cylinder is discharged from it, passing back through the left-hand port and then through the delivery valve into the rising main. On its way to the rising main, the water passes through the lower part of the air-vessel, consequently the outflow of water from the pump is fairly steady under the force of the air in the air-vessel. The outflow cannot be quite steady because of the difference between the effective area of the bucket on one side and that on the other, due to the area of the section of the piston rod. The discharge on the left-hand stroke is expressed by 0·034 D^2LE, and the discharge on the right-hand stroke is expressed by 0·034 $(D^2 - d^2)\ LE$, and if we consider the pump to make N strokes per minute, the average rate of discharge will be—

$$0{\cdot}034LNE \left\{ D^2 - \frac{d^2}{2} \right\} \text{ gal. per minute}$$

Example 74. A Tangye pump has a diameter of 12 in. and a stroke of 2 ft ; the diameter of the pump rod is 3 in., and the pump makes 30 strokes per min. If the volumetric efficiency of the pump is 90 per cent, calculate the discharge in gallons per minute.

Solution. Discharge $= 0{\cdot}034 \times 2 \times 30 \times 0{\cdot}9 \left\{ 12^2 - \frac{3^2}{2} \right\}$

$= 0{\cdot}034 \times 54 \times 140{\cdot}5$

$= 258$ gal. per min. *Ans.*

The discharge of a direct-acting steam pump is dependent on the speed, and the speed depends on the effective pressure of the steam on the piston. When the steam pressure is 50 lb. per sq. in., and the " head " in feet per pound of steam pressure is

6·3, a 12 in. pump having a stroke of 3 ft. and driven by an engine 24 in. in diameter, will discharge 29,300 gal. of water per hour.

Relation of Head to Diameter of Engine and Pump. Given a pump whose steam piston and plunger are of certain dimensions, the head against which the pump will raise water depends (1) on the steam pressure and (2) the relative areas of the steam piston and the plunger. The connection between these quantities may be written as follows:

Total pressure on steam piston = Total pressure on plunger

$$\text{i.e. } \frac{\pi}{4}D^2P = \frac{\pi}{4}d^2 \times 0.434H$$

where D is the diameter of the engine, P the effective pressure of the steam or compressed air in pounds per square inch, d the diameter of the pump, and H the head in feet.

Example 75. A direct-acting pump works under a total head of 180 ft. Its ram is 6 in. in diameter. Compressed air at 60 lb. per sq. in. is available. What must be the diameter of the piston in the compressed air cylinder to make the pump work?

Solution. Neglecting the frictional resistance to the motion of the pump and the effect of the piston rod, we have

$$D^2 = 0.434d^2H \div P$$
$$= 0.434 \times 6^2 \times 180 \div 60$$
$$= 46.87$$
$$D = 6.84 \text{ in. } \textit{Ans.}$$

Example 76. A double-acting pump is 10 in. in diameter and has a stroke of 2 ft. 6 in. It is connected direct to a steam engine having a 20 in. cylinder supplied with steam at 80 lb. per sq. in. by gauge. Assuming that the mean effective pressure of the steam is 50 lb. per sq. in., to what height could such a pump raise water?

Solution. In this case P represents the mean effective pressure, and the solution is obtained by transposition of the foregoing formula, viz.—

$$H = PD^2 \div 0.434d^2$$
$$= 50 \times 20^2 \div 0.434 \times 10^2$$
$$= 50 \times 400 \div 0.434 \times 100 = 461 \text{ ft. } \textit{Ans.}$$

As has already been shown, the result is quite independent of the length of the stroke.

Action of the Tangye Steam-engine. Fig. 182 is a section of the engine, and is intended to illustrate the action of the slide valve. The slide valve *D* is shown admitting steam to the right-hand end of the cylinder, and consequently the piston may be considered to be moving from right to left. When the

FIG. 182 SECTION OF TANGYE STEAM-ENGINE

piston approaches the end of its stroke, and by contact lifts the left-hand tappet valve *F*, steam is exhausted from the left-hand plunger cylinder *L*, through the passage *J*, thus putting in motion the plunger *C* and the slide valve *D*, and thereby reversing the pump The steam by which the plunger and valve are operated is admitted by the small holes *K* in the ends of the plunger cylinders. The lever *H* is used when starting up the pump, but is not operated during the normal working of it.

Condensation of Exhaust Steam. The primary object of a

condenser as attached to an underground pumping engine is to dispose of the exhaust steam in such a manner as will prevent it being discharged from the engine direct into the airway leading to the pump, even if that should be the return

FIG. 183. LLOYD'S EXHAUST STEAM CONDENSER

airway. It is unnecessary to dwell on the obvious objections to the use of an open exhaust. There are really three satisfactory methods of condensing the exhaust steam, viz.—

1. To exhaust the steam into the suction pipe.
2. To exhaust it into surface condenser.
3. To exhaust it into a jet condenser.

A secondary, but not less important, object of a condenser is to produce a vacuum, and thereby reduce the back pressure against the engine. The reduction of the back pressure from about 17 lb. per sq. in. to about 3 lb. per sq. in. is equivalent to adding 14 lb. per sq. in. to the mean effective pressure of the steam on the piston.

Floyd's Exhaust Steam Condenser. This condenser is a useful adjunct to the "Special" steam pump when used in mine workings or other confined positions where a condenser is essential. It is attached to and practically forms part of the suction pipe, as is shown by Fig. 183. The exhaust steam is conveyed into it, and there it is condensed by the water which is being drawn into the pump. The pump bucket used with this condenser is made of cast-iron with brass rings, the usual leather-packed bucket not being suitable.

The "Tipton" Direct-acting Steam Pump. This pump, which is made by Messrs. Lee, Howl & Co., Ltd., Tipton, Staffs., is designed on somewhat different lines from those already described, and is used to raise water against heads varying from 300 to 1500 ft. Fig. 184 shows the component parts of this type of pump, and it is seen that two working barrels, secured together by stanchions, are mounted upon a cast-iron bed-plate in which a portion of the suction pipe is an integral part. The double-acting ram works through gun-metal bushed glands and gun-metal neck rings. The valve boxes are separate and interchangeable, each valve being provided with an independent cover. The valve boxes are connected together by collecting pipes, and it is seen that not only is there an air-vessel attached to the delivery collecting pipe, but there is one attached to the suction pipe as well. The pump is regularly fitted with cast-iron ram and steel pump rod, the valve boxes being fitted with gun-metal valves and seatings, but in special cases the ram may be encased in a gun-metal liner and have a manganese bronze pump rod. It is made in sizes varying from 4 to 12 in. in diameter to be driven by engines varying from 7 to 28 in. in diameter, the stroke being 12 in. in the smallest size, and 24 in.

in others. The Tipton pump may be driven by steam, but if it should be thought undesirable to convey steam into underground workings on account of the danger which might possibly be attached to such procedure, the pump may be driven by compressed air; indeed, this pump has found an extensive use in fiery mines where conditions of temperature

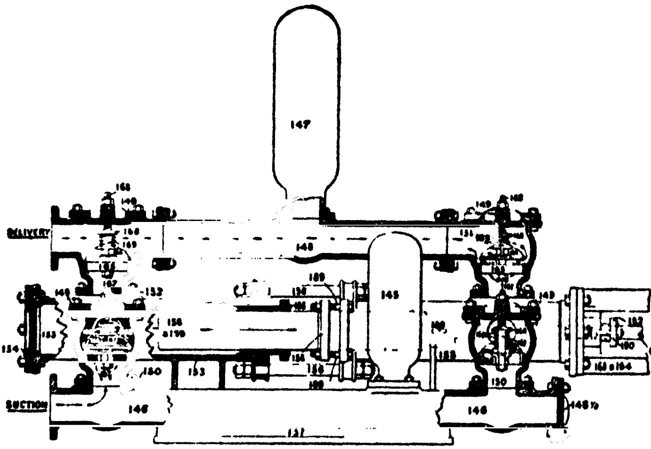


FIG. 184 "TIPTON" STEAM PUMP

and humidity render it imperative that compressed air should be used as the motive power.

Use of Compressed Air as Motive Power. As the temperature of air increases when it is compressed, so does the temperature fall when the air is expanded, and the final temperature may be lower than 32° F., in which case freezing of the moisture in the air will take place unless steps have been taken to dry the air. The change in temperature is found by the formula $T = P^{0.29} \times t$, where T is the absolute temperature in degrees Fahrenheit of the air before expansion, where t is the absolute temperature of the air after expansion, and P is pressure drop in atmospheres.

If we consider the case in which compressed air at 60 lb. per

sq. in. and 70° F. is exhausted at full pressure into the atmosphere then the drop in temperature is found as follows—

$$t = \frac{T}{P^{0 \cdot 29}} = \frac{459 + 70}{\left(\frac{60}{15}\right)^{0 \cdot 29}} = \frac{529}{4^{0 \cdot 29}} = 353 \cdot 9^\circ \text{ F.}$$

The temperature in the exhaust ports of an air-engine working under such conditions would be − 105·1° F., and consequently the moisture in the air would be converted into ice, which would choke the ports and render working of the engine most unsatisfactory and inefficient. It is usual to supply air-driven pumping engines with the full pressure of air for almost the whole length of the stroke, so that there is always a very grave risk of interruption of the working of such engines unless (1) the air is dried before it reaches the engines, (2) the temperature is increased by passing the air through a heater of some form. The former precaution is that usually taken. The moisture of the air may be effectually removed by means of such a device as the "Huwood" air-drier,[1] which is manufactured by Messrs. Hugh Wood & Co., Ltd., Newcastle-on-Tyne.

Rotative Reciprocating Pumps. Rotative reciprocating pumps are distinguished from direct-acting, non-rotative pumps by the fact that the reciprocating motion of the former is accompanied, or is produced, by the rotation of a flywheel or a crank, whereas the motion of the latter is one of reciprocation alone. This is a statement of the essential idea of distinction, and, obviously, it includes single-acting, double-acting, differential, and three-throw pumps. In developing the discussion of the subject the opportunity is taken to study the functions of air-vessels and the conditions which lead to the occurrence of cavitation in the working of high-speed pumps, and it will be shown that the greater the speed of reciprocating pumps the more necessary it is that the valves should be operated mechanically, instead of being allowed to open and close by the reversal of the direction of motion of the water in the pump. Pumps of this class are eminently

[1] See Chapter IX.

suitable for dealing with water at points remote from the shaft, principally because they may be driven by electricity, but, even when for economic reasons it might be desirable to employ the electrical system of transmitting power, other conditions may preclude the possibility of using electricity because of the danger which attends its use The danger of igniting firedamp in remote parts of fiery mines may be regarded as real, but the electrical transmission of power is so much superior to

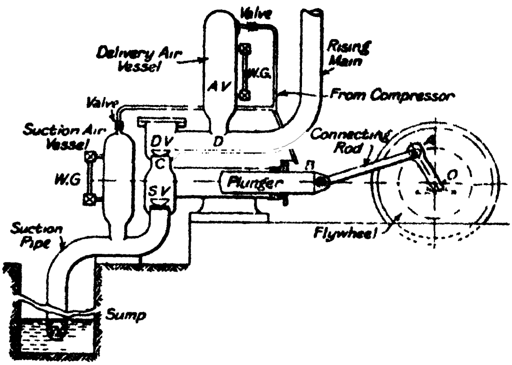


FIG. 185 SINGLE-ACTING PUMP

the other methods which are at present available that every effort should be made, by thorough supervision of electrical plant and the ventilating arrangements, to make the occurrence of an ignition of firedamp a remote possibility. Men of experience in fiery coal mines know that the dead burden of the cost of pumping water is capable of being lightened by the use of electrical power without sacrificing anything in the interests of safety.

Single-acting Pump. Fig. 185 is a diagrammatic representation of a single-acting pump which is driven by the rotation of a crank OA, the motion of the crank being communicated to the plunger by a connecting rod AB. As the crankshaft rotates the plunger reciprocates in the barrel of the pump. While the outward stroke of the plunger is being made the

pressure within the pump is diminished, and the pressure of the atmosphere on the surface of the water in the sump causes the water to flow through the suction valve *SV* into working barrel, and when the direction of motion of the plunger is reversed, the suction valve closes, and the delivery valve *DV* opens to allow the water displaced by the plunger to pass, in part, into the rising main, and also into the air-vessel *AV*. In considering further action of the pump it is seen that during the suction stroke the pressure within the

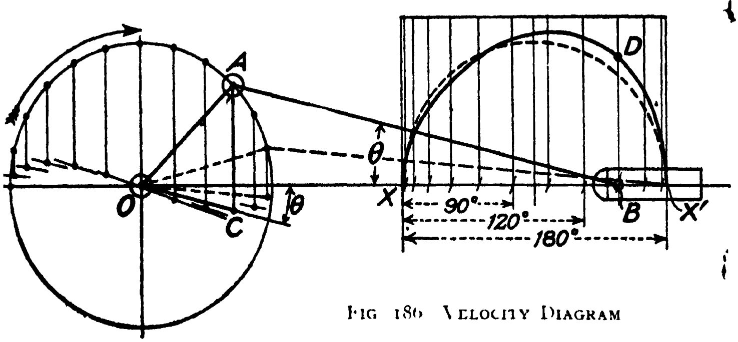


FIG. 186 VELOCITY DIAGRAM

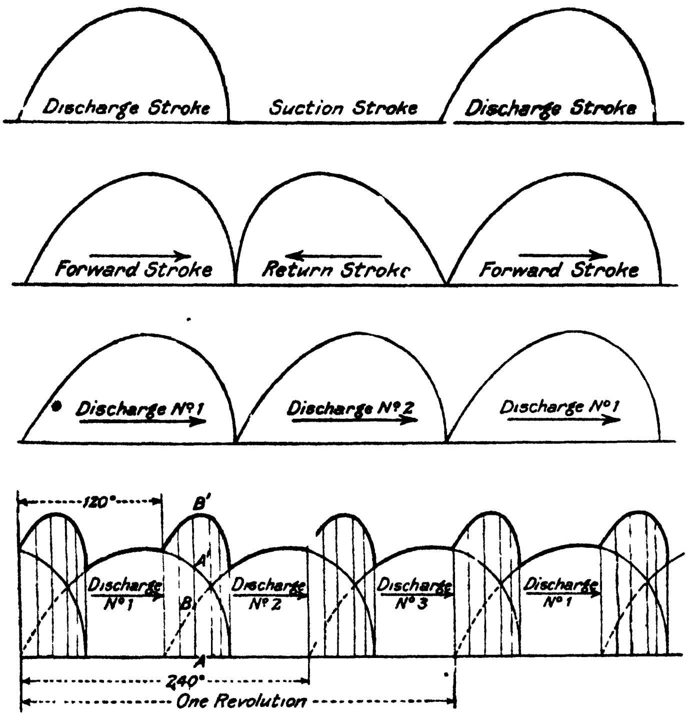
working barrel is less than atmospheric pressure, and that during the discharge stroke the pressure is dependent mainly on the head against which the pump is working.

Relation of Velocity of Plunger to Velocity of Crank Pin. Fig. 186 shows a curve of plunger velocities plotted on a base of horizontal displacement between dead centres, and if it is assumed that the water is accelerated at the same rate as the plunger the diagram may be considered (for it is really) a flow diagram. The value of such a diagram lies in its revelation of the source of inertia stresses set up in a pump having no air-vessels by reason of the fluctuations of velocity in the water discharged into the rising main. It will be seen that as the crank pin revolves from the left-hand dead centre to the right-hand one, the plunger moves from left to right at a varying velocity, being zero at the dead centres and greatest when the

crank and connecting rod are at right angles. When the crank pin arrives at any position such as A, the corresponding linear velocity of the plunger is determined by drawing OC parallel to AB, and then drawing BD equal in length to AC. The solid curve XDX^1 was obtained by taking the position of the crank pin at intervals of 15°, the ratio of AB to OA being 3 to 1. The crank pin was assumed to rotate at uniform speed, and had it been further assumed that the connecting rod was of infinite length, the curve of velocity would then have become a semicircle, thus denoting the plunger to reciprocate with simple harmonic motion. The flow diagram has been constructed in order that some consideration should be given to the fluctuations of velocity and inertia stresses in pumps of the types commonly used in mine drainage. Fig. 187 gives the curve showing the theoretical relative velocity of the single-acting pump, and it shows clearly that while the velocity is positive and constantly varying during the delivery stroke it is zero during the suction stroke It is obvious that the load factor of such a pump is low, and because of the unbalanced load arising from the intermittent action of the pump it is usual to attempt to equalize the load by the attachment of a flywheel to the pump. Fig. 188 represents the curve that might be constructed to show the variations of velocity in the working of a double-acting pump of the differential type. The fluctuations of velocity are less violent than those shown in the preceding figure, and when such a pump is fitted with suitable air-vessel the fluctuations are still less pronounced. The flow diagram for a single-acting pump having two plungers connected to cranks 180° apart is shown in Fig. 189, and it is seen to resemble closely the flow diagram for the double-acting pump. Fig. 190 is the flow diagram of the well-known three-throw pump which has cranks at angles of 120° apart, and it is seen that the resultant curve of velocity is obtained by compounding the elementary curves where these overlap. The ordinate AB from the discharge diagram of No. 2 plunger is added to the corresponding ordinate of the discharge diagram of No. 1 pump. This gives the point B^1

on the resultant curve. The fluctuations of velocity are less pronounced than those which characterize the double-acting pump.

Air-vessels. The diagrams of velocity show that when a pump is not fitted with air-vessels there are considerable



FIGS. 187–90. DISCHARGE DIAGRAMS

variations of velocity of the plunger, or plungers, and of the water passing through the pump In some cases the velocity of the plunger changes rapidly, and as the production of acceleration implies the application of force, by the plunger upon the water or the water upon the plunger, it appears desirable that the effects of high accelerating forces should be

avoided. The action of a plunger pump is fundamentally intermittent, but it should be the aim of the engineer to use such a pump in such a manner that the flow of water through it might for all practical purposes be regarded as constant.

Pearn Double-ram Pump. So far as the mechanical construction and the materials used in the construction of this

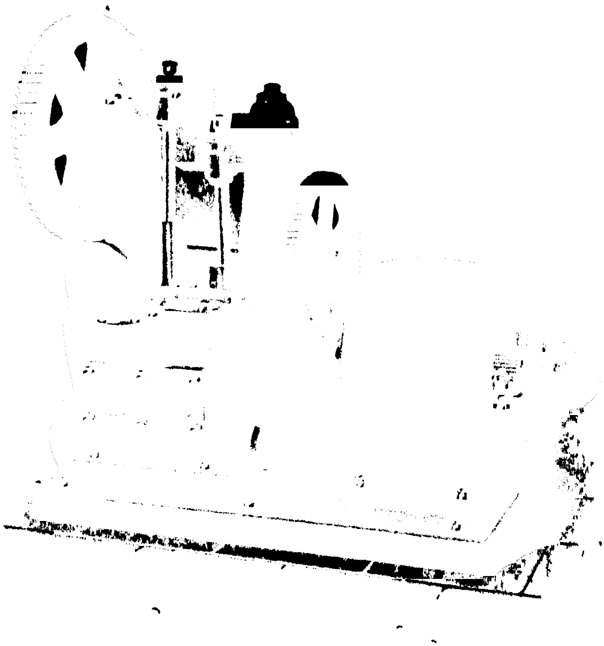


FIG. 191 PEARN DOUBLE-RAM PUMP

pump are concerned, it bears a close resemblance to the single-ram pump. Fig. 191 shows that in this pump there are two rams connected to the crankshaft at angles of 180° apart. The crankshaft is supported on two bushed bearings at the tops of two triangular standards, and the air-vessel is formed to act as the means of connecting the delivery pipe to the pump, thus making for compactness in design. There are two

effective strokes per revolution of the crankshaft, and consequently the discharge from the pump is less intermittent than it is from the single-acting ram pump. On account of the steadier flow of water from the pump there is not the same need for a flywheel and a delivery air-vessel, but since the cranks are on opposite dead centres at the same time, it is obvious that the flywheel may still function usefully as a balancer of load and the air-vessel as a regulator of flow.

Power. The power required to drive a pump depends upon two things: (1) the discharge; (2) the head. Expressed in the simplest terms, the horse-power required to drive a pump of any kind is given by the formula—

$$\text{Horse-power} = \frac{10\ GH}{33{,}000E}$$

Where G discharge in gallons per minute

H head in feet (including allowance for friction)

E efficiency of machine.

Example 77. A double-ram pump 5 in. in diameter has a stroke of 6 in. and runs at 80 r p.m. If the volumetric efficiency of the pump is 0·85 and the head is 150 ft., determine the horse-power of the electric motor that would be required to drive the pump, assuming the mechanical efficiency of the pumping gear is 0·7.

Solution. The answer to this problem is divisible into two parts, the first being concerned with the discharge, the other with the determination of the horse-power of the motor

$$\begin{aligned} G &= 0{\cdot}034d^2L\,.\,NE \\ &= 0{\cdot}034 \times 5^2 \times \tfrac{6}{12} \times 80 \times 2 \times 0{\cdot}85 \\ &= 57{\cdot}8 \text{ gal. per min.} \end{aligned}$$

$$\text{H.p} = \frac{10 \times 57{\cdot}8 \times 150}{33{,}000 \times 0{\cdot}7} = 3{\cdot}75. \quad \textit{Ans.}$$

"Reliable" Double-acting Steam Pump. Messrs. Joseph Evans & Sons (Wolverhampton), Ltd., are the makers of this pump, which is specially adapted for pumping against heads approaching 1000 ft., and being of the outside-packed ram type, it is especially suitable for dealing with gritty water.

The steam and water ends of the pump are of forms that are now familiar to us, but we must take note of the method which has been employed to produce a flywheel pump of compact design. It is seen in Fig. 192 that the piston rod and the pump rod are connected by what is technically called a "kite." The connecting rod, by which the motion of the engine is communicated to the flywheel, is connected to the kite pin, 166, at one end and to the crank at the other. The crankshaft is carried in two bearings mounted on the bed-plate, and the flywheel is fitted in an overhung position to one end of the crankshaft. This arrangement enables the flywheel to be connected to what would otherwise be a direct-acting engine. The pump is a double-acting one, and it is made in sizes varying from 3 to 14 in. in diameter, with stroke varying from 6 to 24 in.; the diameter of the steam-engine varying from 5 to 24 in.

Mechanical Efficiency of Pumping Plant. The essential idea of the mechanical efficiency of any machine is expressed by the ratio of output to input, and when that ratio is multiplied by 100 the result is given as a percentage. In the particular case of a pumping plant it is necessary in determining the overall mechanical efficiency to ascertain the input of power to the motor or engine and the work done on the water discharged, which must include the work done against friction, then the overall mechanical efficiency $= \frac{10GH}{33{,}000 \times \text{input h.p.}}$, but the efficiency of the pump itself is given by the expression $\frac{10GH}{33{,}000 \times \text{input h.p.} \times e}$, where e is the mechanical efficiency of the motor or engine and the gear, if any. The mechanical efficiency of a steam-engine may be fairly assessed at about 80 per cent, and an electric motor at about 95 per cent, but it must be remembered that in both cases the actual efficiency depends on whether the machine is running on light load or full load. The efficiency of single-reduction gearing may be taken at 95 per cent, on the assumption that there is perfect meshing of the teeth, the efficiency of double-reduction gear

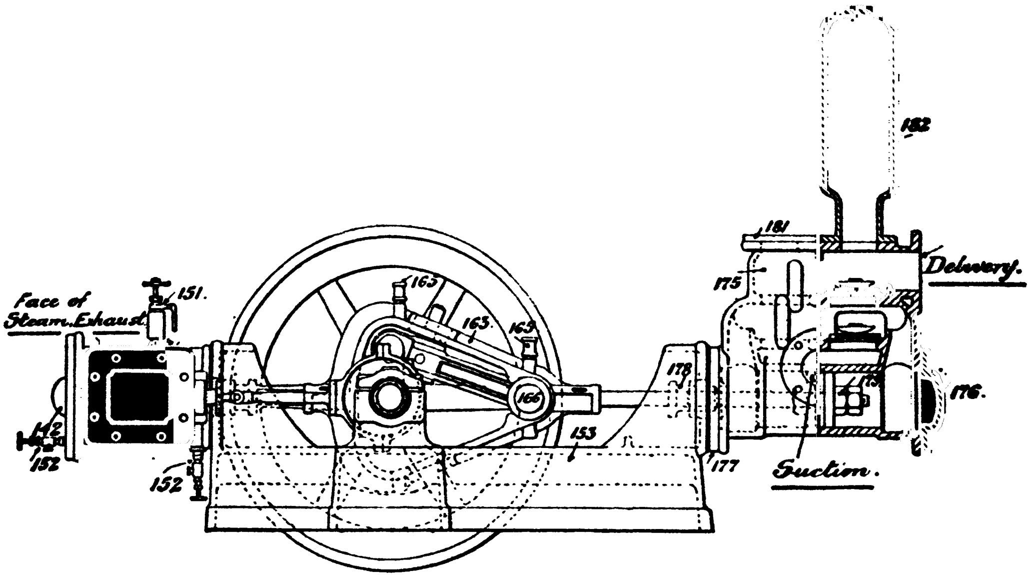


FIG. 192. " RELIABLE " STEAM PUMP

may be taken at about 90 per cent, and the efficiency of belts and rope gearing may be taken at 95 per cent.

Example 78. A differential ram pump 5 in × 7 in × 9 in. stroke, running at 160 r p m, is driven by an electric motor through single-reduction gear, the input horse-power of the motor being 37. The head of the water on the pump (including friction) is 435 ft. Find the mechanical efficiency of the pump and the overall efficiency of the plant. $e = 90\%$

Solution. In determining the discharge of a differential ram pump, we may look upon the pump as being a single-acting pump having a ram whose diameter is the greater of the given dimensions or as a double-acting pump whose ram has the smaller dimension as diameter. For the purpose of this example, we shall take the latter view, and also assume the volumetric efficiency to be 100 per cent, therefore—

$$G = 0.034 d^2 L N E$$
$$= 0.034 \times 5^2 \times \tfrac{9}{12} \times 2 \times 160 \times 1$$
$$= 204 \text{ gal per min.}$$

The output horse-power

$$= 10 G H \div 33\,000$$
$$= 10 \times 204 \times 435 \div 33{,}000$$
$$= 27$$

Mechanical efficiency of pump

$$= \frac{\text{Output h p} \times 100}{\text{B h p of motor and gear}}$$
$$= (27 \div 0.9 \times 37)100$$
$$= 81\%$$

Overall efficiency of plant

$$= (27 \div 37)100$$
$$= 73\%$$

A knowledge of the mechanical efficiency of a pump, although the efficiency may vary within limits determined by the condition of repair of the pump, is useful in that it enables prospective purchasers to work out the commercial efficiency of the pumping plant, a figure which is influenced by the actuarial factors of depreciation, interest, and amortization, and the technical factor or running cost.

Three-throw Ram Pump. This pump consists essentially of an arrangement of three single-acting rams which are operated

by cranks set at angles of 120°. The suction and delivery pipes of the separate pumps are connected together by common suction and discharge pipes, to which are attached suitable air-vessels. The valves, although they are usually of ample dimensions, are uncontrolled, consequently the speed is limited to that which enables the valves to operate without the occurrence of excessive slip. Fig. 193 shows the main features of the treble ram pump made by Frank Pearn & Co., Ltd., Manchester. The barrels and valve chambers are made of cast-iron, and the valves and valve seats are made of gun-metal or other suitable material. The rams, which are made of close-grained cast-iron, work through gun-metal neck rings and cast-iron glands. The crossheads work in circular bored guides, and the cranks of the slab type are attached to the crankshaft, which is carried in four bearings having adjustable gun metal liners. As will be seen from the figure, the pump is of strong construction to enable it to deliver water against high heads. The pump may be arranged to be driven by spur gearing, by belts, or by ropes. In dry situations, belt- or rope-gearing may be used, but in wet places where space is of moment the spur-gearing is most advantageous. A decided advantage of the treble ram pump is that the discharge is practically constant, thus admitting of electrical driving. The advantage of the electrical drive is important in relation to the removal of water from places that are to the dip of, and remote from, the shaft. The performance of such a pump under normal working conditions is bound to vary with the state of repair, but the following figures, culled from *Experiments with Electrically-driven Pumps*, by T. L. Galloway, are indicative of what may be expected from such a pump. (See page 82, Vol. XXXVI, *Trans. I. Min. E.*)

Pump 9 in. in diameter, with three rams having 12-in. stroke—

Static head	383 ft.
Friction head	12 ,,
Total . . .	395 ft.

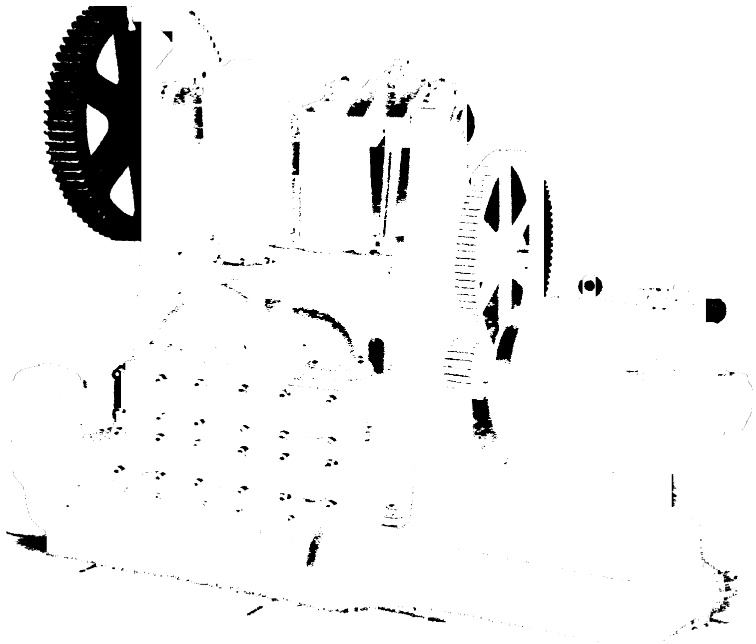


FIG 103 PEARN'S THREE-THROW RAM PUMP

Speed of pump	57 r.p.m.
Displacement	462 gal. per min.
Actual discharge	429 ,, ,,
Slip	33 gal. per min.

Which is equal to about 7%.

Useful work	52·6 h.p
Input horse-power to motor	70·8 ,,
Useful effect of plant	72% ,,

Treble Ram Pump with Flooded Suction Valves. It is probably true to say that most of the breakdowns in rotative reciprocating pumps are due to water-hammers arising from attempts to run pumps at speeds beyond the limiting speed at which cavitation takes place. If it were possible to have the pump placed below the level of the water in the sump, the suction valves would at all times be drowned, and cavitation, with consequent water-hammer, would be prevented. Repairs to the pump would be less frequent, and the capacity of the pump might be increased by running it at the greater permissible speed. It is not always possible to arrange to have the sump at higher level than the pump, but Fig. 194 shows the method adopted by Messrs. Lee, Howl & Co., Ltd., Tipton, Staffs., to attain the same end.

At one side of the pump and driven from the crankshaft a separate ram pump is fitted; this pump is used for drawing water up the suction pipe only, and delivering it into the open-top tank fixed at the back of the high lift pumps, to the suction inlets of which it is attached. The tank is somewhat higher than the delivery valve box of the high lift pumps, and when full of water the whole of the pump valves are flooded or submerged, and in this condition permit of a much higher velocity of water through them than can be obtained in an ordinary pump, in the barrel of which a high pressure and a state of vacuum have to alternate at every revolution. In order to keep the tank quite full the suction pipe is made of slightly larger capacity than that of the three lifting rams, and any excess of water is allowed to flow back to the source of supply through an outlet near the top; the suction pump is very simple,

FIG 194. TIPTON FLOODED-SUCTION PUMP

being fitted with two only india-rubber disc valves working on grid seats

Example 79. A three throw pump has single-acting rams 12 in. in diameter and 18 in stroke The crankshaft makes 30 r p m Assuming that the slip amounts to 10 per cent of the theoretical displacement, determine the weight of water discharged by the pump per hour

Solution.

Amount of discharge per ram per minute

$$= 0.034d^2LNE \text{ gal}$$

Amount discharged by pump per hour

$$= \frac{3 \times 0.034d^2LNE \times 60 \times 10}{2240}$$

$$= \frac{3 \times 0.034 \times 12^2 \times \frac{18}{12} \times 30 \times 1 \quad \times 60 \times 10}{2240}$$

$$= 159 \text{ tons}$$

Centrifugal Pump. In its simplest form the centrifugal pump consists of two main parts (1) the impeller (2) the casing The impeller is usually made of phosphor bronze in order that it may offer a high resistance to a mechanical abrasion by dirty water and be proof against the corrosive effects of water having acid properties The impeller is mounted upon a steel shaft which passes through the casing the water being sealed off by a packed gland fitted with a water seal from the delivery main, while the bearing proper is usually carried on an extension of the end cover The other end of the shaft is carried in a sleeve bearing composed of a bushing in a water-tight cap bolted to the casing, lubrication being effected by means of a Stauffer grease cup feeding through the end of this cap The casing is of the volute pattern, designed to convey the entering water to the eye of the impeller by double-suction inlets, and the volute chamber has guide vanes cast in it Fig 195 is a diagrammatic representation of the principal features of the centrifugal pump When the impeller is caused to rotate in clockwise direction water is drawn into the eye of the impeller from the suction inlet *A* and then it

is discharged from the impeller B through the guide vanes C into the volute chamber D, to which the discharge pipe E is attached. It may at once be stated that the centrifugal pump should have a short suction pipe and a low head if the best results are to be obtained. If the pump is used in de-watering a dip working it may not be possible to have a short suction pipe, especially if the position of the pump is temporarily

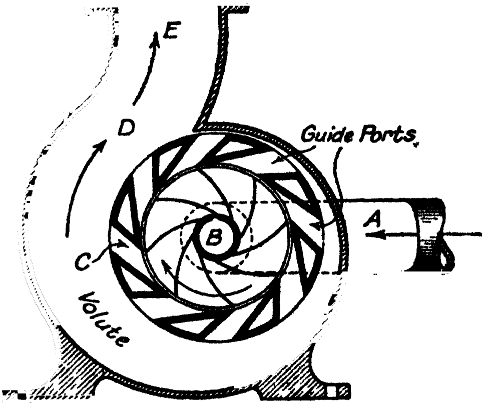


FIG. 105 CENTRIFUGAL PUMP

fixed and the water is allowed to recede from it, but experience dictates that effective work may be done even when the suction head approaches 20 ft and the slope 1 in 5. The shorter the suction pipe the less trouble is experienced in starting up the pump from the dry condition.

Simple Theory of Centrifugal Pump. Fig. 106 shows the vanes of an impeller at a certain position in their clockwise rotation, and it is to be assumed that the water is taken up by the root of the blade without shock. It is deducible from the principles of mechanics that the work done on the water by the impeller is $\frac{V_1 v_1}{g}$ ft.-lb. per pound of water flowing through the pump. If H_s be the height of the centre of the impeller above the free surface of the water in the sump, and H_d is the height

of the point of the discharge above the centre of the pump, and V_d is the velocity with which the water is discharged from the delivery pipe, the work done on each pound of water is—

$$H_s + H_d + \frac{V_d^2}{2g}$$

and therefore $\frac{V_1 v_1}{g} = H_s + H_d + \frac{V_d^2}{2g} = H,$

the theoretical lift of the pump. Let $(180° - \phi)$ be the angle between the direction of the vane at exit and the direction of

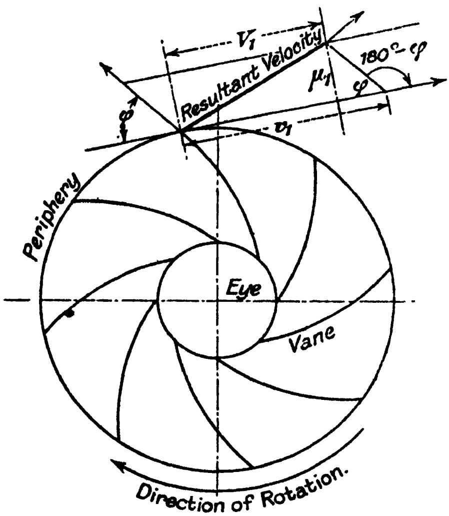


FIG. 196. IMPELLER DIAGRAM

motion, then the tangential component of the resultant velocity will be

$$V_1 = v_1 - \mu_1 \cot \phi$$

hence, $H = \frac{V_1 v_1}{g} = \frac{v_1 (v_1 - \mu_1 \cot \phi)}{g}$, ... (1)

and since the radial velocity μ_1 is given by the quotient of Q_1,

the discharge in cu. ft. per sec., and A_1 the circumferential area in square feet, the theoretical lift

$$H = \frac{v_1^2 - v_1 \dfrac{Q}{A} \cot \phi}{g} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This formula shows that the theoretical lift of a centrifugal pump depends on the peripheral speed of the impeller and the inclination of the vane at the circumference of the impeller. For any given head H the values of V_1 and v_1 must be such as to give a product equal to gH, and as the value of V_1 is related to the angle ϕ, it is possible to choose the value of ϕ to give a certain relationship between v_1 and H. For a given value of H the greater the angle ϕ the less the value of v_1.

Manometric Efficiency of Centrifugal Pump. The ratio of the gross lift of a pump to the theoretical lift is an expression of the manometric efficiency of the pump, i.e.,

$$\eta = \frac{h}{H} = \frac{gh}{v_1^2 - v_1 \dfrac{\phi}{A} \cot \cdot \phi} \quad . \quad . \quad . \quad . \quad (3)$$

In pumps of modern design the value of η may vary from 0·6 to 0·85, being greater the less the angle ϕ. In computing h the gross head, allowance must be made for the loss of head by friction in the suction and discharge pipes, and the head $V_d^2 \div 2g$ should always be considered as an external loss, thus —

$$\eta = g \frac{\left(h_a + h_s + h_d + \dfrac{V_d^2}{2g}\right)}{v_1^2 - v_1 \dfrac{Q}{A} \cot \cdot \phi} \quad . \quad . \quad . \quad . \quad (4)$$

is a complete statement of the manometric efficiency.

Design of Centrifugal Pump. In proceeding to design a centrifugal pump to discharge a certain quantity Q of water

against a certain actual head h_a, one must first of all consider what the gross head h is most likely to be, for the gross head

$$h = \frac{e(v_1^2 - v_1\,\mu_1 \cot \phi)}{g}$$

If, now, one decides that the radial velocity u is not to exceed something between 3 and 10 ft. per sec., and suitable values are assigned to any other two quantities, the remaining quantity can be found. It seems that, in the light of experience, one need not hesitate to assign a value to ϕ, and knowing the actual head, the gross head may be readily calculated with

HEAD IN FEET TO OVERCOME FRICTION, PER YARD LENGTH OF PIPE

Imperial Gallons per Minute	Diameter of Pipe in Inches												
	1	1½	2	2½	3	4	5	6	7	8	9	10	12
5	·102	·013	·003	·001									
10	·411	·054	·013	·004	·002								
15	·925	·121	·029	·009	·004								
20	1·64	·216	·051	·017	·006	·001							
30	—	·487	·115	·038	·015	·003	·001						
40	—	·867	·205	·067	·027	·006	·002						
50		1·35	·321	·105	·042	·01	·003	·001					
60	—		·463	·151	·06	·014	·004	·002					
70	—	—	·630	·206	·083	·02	·006	·002	·001				
80	—	—	·823	·269	·108	·025	·008	·003	·002				
90		—	1·04	·341	·137	·032	·01	·004	·002	·001			
100			1·28	·421	·169	·04	·013	·005	·002	·001			
120	—			·606	·243	·057	·019	·007	·003	·002	·001		
140		—	—	·825	·332	·070	·025	·010	·005	·002	·001		
160	—			1·07	·433	·102	·033	·013	·006	·003	·002	·001	
180				1·36	·540	·131	·042	·017	·007	·004	·002	·001	
200		—	—		·677	·160	·052	·021	·009	·005	·003	·002	
220		—	—	—	·819	·194	·063	·025	·011	·006	·003	·002	
240	—			—	·975	·231	·075	·030	·014	·007	·004	·002	·001
260	—			—	1·14	·271	·089	·035	·016	·008	·005	·003	·001
280	—	—	—	—	1·32	·315	·103	·041	·010	·009	·005	·003	·001
300	—		—	—	—	·361	·118	·047	·022	·011	·006	·004	·001
350	—	—	—	—	—	·492	·161	·065	·030	·015	·008	·005	·003
400	—	—	—	—	—	·643	·21	·084	·039	·020	·011	·006	·002
500	—	—	—	—	—	1·00	·329	·132	·061	·031	·017	·010	·004
600		—	—	—	—	1·44	·474	·190	·088	·045	·025	·014	·006
700	—		—	—	—	—	·645	·259	·120	·061	·034	·020	·008
800	—	—	—	—	—	—	·842	·337	·156	·080	·044	·026	·010
900		—	—	—	—	—	1·06	·425	·198	·101	·056	·033	·013
1000	—	—	—	—	—	—	1·31	·529	·244	·125	·069	·041	·016
1100	—		—		—	—	—	·640	·296	·152	·084	·050	·020
1200	—	—	—	—	—	—	—	·762	·352	·180	·100	·059	·023
1300	—	—	—	—	—	—	—	·894	·414	·212	·117	·070	·027
1400	—	—	—	—	—	—	—	1·04	·48[illegible]	·246	·130	·080	·032
1500	—		—	—	—	—	—	1·19	·55[illegible]	·2[illegible]3	·[illegible]50	·003	·037
1600	—	—	—	—	—	—	—	1·35	·627	·322	·178	·105	·042
1700	—	—	—	—	—	—	—	—	·7[illegible]8	·363	·201	·118	·047
1800	—	—	—	—	—	—	—	—	·79[illegible]	·407	·225	·133	·053
1900	—	—	—	—	—	—	—	—	·884	·453	·251	·148	·056
2000	—	—	—	—	—	—	—	—	·979	·502	·270	·164	·069

NOTE.—These figures are based on the formula $H = \dfrac{G^2\,L}{(3d)^5}$

reasonable precision. It is necessary to take into account and allow for the resistance of foot valve, strainer, bends, elbows, or tees. The equivalent lengths of straight pipe of same diameter which would cause the same frictional resistance as the specified fittings are as follows—

	Ft
Foot valve and strainer	45
Sluice valve, full open	2
Valve with hinged flap	10
Bends (r 3 diameters)	3
Round elbows	9
Sharp elbows and tees	18

The loss of head due to friction of water in pipes is given in the table on the preceding page

Example 80. Calculate the total head against which a centrifugal pump will have to discharge 500 gal of water per min., given the following particulars static suction lift 10 ft , static delivery head 50 ft , one bend in suction pipe and one valve with hinged flap The velocity of the water in discharge and suction pipes is to be 5 ft per sec.

Solution. Diameter of suction and discharge pipes

$$Q \quad \frac{\pi}{4} d^2 \quad 60v \times 6\tfrac{1}{4} \text{ gallons}$$

$$\therefore d \quad \sqrt{\frac{4}{\pi} \times \frac{Q}{60v} \times \frac{4}{25}}$$

$$= \sqrt{\frac{4}{3 \cdot 14} \times \frac{500}{60 \times 5} \times \frac{4}{25}} = 0\ 58 \text{ ft}$$

The diameter of the discharge and suction pipes may be taken as 7 in.

Equivalent length of suction pipe

	Ft	
Suction pipe	10	23 ft
Hinged flap valve	10	
Bend	3	
Friction (23 ft at 0 061 ft per yd) .	0·46 ft.	
Total . . .	23·46 ft	

Equivalent length of delivery pipe

	Ft.	
Static head	50	52 ft.
Sluice valve	2	
Friction (53 ft. at 0·061 ft per yd) . .		1·1 ft.
Total . . .		53·1 ft

Head equivalent to $v_o^2 - 2g = 5^2 - 2 \times 32{\cdot}2$

$$= 25 - 64{\cdot}4 = 0{\cdot}39 \text{ ft}$$

The gross head, therefore, is the sum of 23·46, 53·1, and 0·39 which is just 77 ft

Example 81. Calculate the peripheral speed and diameter of the impeller of a centrifugal pump to raise 500 gal per min, against a gross head of 77 ft Let the angle ϕ be 40° and the manometric efficiency be 0 6, and assume the area of the circumferential opening to be such that the radial velocity of the water at exit is 5 ft. per sec.

Solution. Using formula (5), we get

$$77 = 0{\cdot}6 \frac{(v_1^2 - v_1 \times 5 \cot 40^\circ)}{32{\cdot}2}$$

and $v_1^2 - v_1 \times 5 \cot . 40^\circ = 77 \times 32{\cdot}2 - 0{\cdot}6 = 4132{\cdot}3$

$\therefore\ v_1^2 - v_1 \times 5 \times 1{\cdot}1918 = 4132{\cdot}3$

and $v_1^2 - 5{\cdot}959 v_1 \qquad = 4132{\cdot}3$

$$\text{hence } v_1 = \frac{-(-5{\cdot}959) \pm \sqrt{(-5{\cdot}959)^2 - 4 \times 1 \times (-4132{\cdot}3)}}{2}$$

$$= \frac{5{\cdot}959 \pm 1287}{2} = 67\ 3 \text{ ft per sec.}$$

In Example 80 it was found necessary to have 7-in suction and discharge pipes, therefore the eye of this pump would most likely have the same diameter, and, as the ratio of the diameter of the eye of a centrifugal pump to the diameter of the impeller is 1 to 2 or 1 to 3, the impeller may have a diameter between 14 in and 21 in It is worthy of note, as a modern development of the design of centrifugal pumps, that the ratio of eye diameter to impeller diameter in the pumps made by Messrs Amag-Hilpert, of Nuremberg, for the Rand Water Board was more nearly 3 to 4. If it is decided that the diameter of the impeller in this case is

1·5 ft., then the speed of the pump in revolutions per minute would be

$$\frac{60 \times 67{\cdot}3 \times 7}{22 \times 1{\cdot}5} = 857$$

Starting a Centrifugal Pump. When it is remembered that a centrifugal fan running at much the same peripheral speed as a centrifugal pump produces a depression of a few inches of water, the necessity for priming the pump before starting will be readily understood. In order that that may be done the pump is usually fitted with a foot valve and a gate or sluice valve at the junction of the pump with the rising main. A relief cock is fitted to the top of the casing, and a by-pass pipe is connected to the pump and delivery pipe to bridge the sluice valve. In priming the pump, the priming water is conveyed through the by-pass and by-pass valve into the pump chamber, the air within the chamber being expelled through the relief cock When the casing has been filled completely with water the relief cock and by-pass valve are closed, then the impeller is run up to normal speed. When that condition has been attained the sluice valve is gradually opened and the water rises in the discharge column until it reaches the exit.

The Turbine Pump. The underlying principle of the turbine pump is similar to that of the centrifugal pump, for in the case of both types of pump water enters the eye of the impeller at a low velocity and is thrown off from the periphery at a high velocity, and the kinetic energy of the water passing from the impeller is converted into pressure energy in the volute chamber. It has been shown that when the peripheral speed of the impeller is 67·3 ft. per sec., a single-stage pump can deliver water against a gross head of 77 ft., and at higher peripheral speeds up to about 200 ft. per sec., correspondingly greater heads can be negotiated. A common gross head per stage is about 150 ft., thus if it were necessary to raise water by a turbine pump to a gross height of 1000 ft. it would probably be necessary to have a turbine consisting of six cells or impellers, and if the pump was run at a lower speed it would be suitable for, say, a head of 700 ft. Fig. 197 shows a section

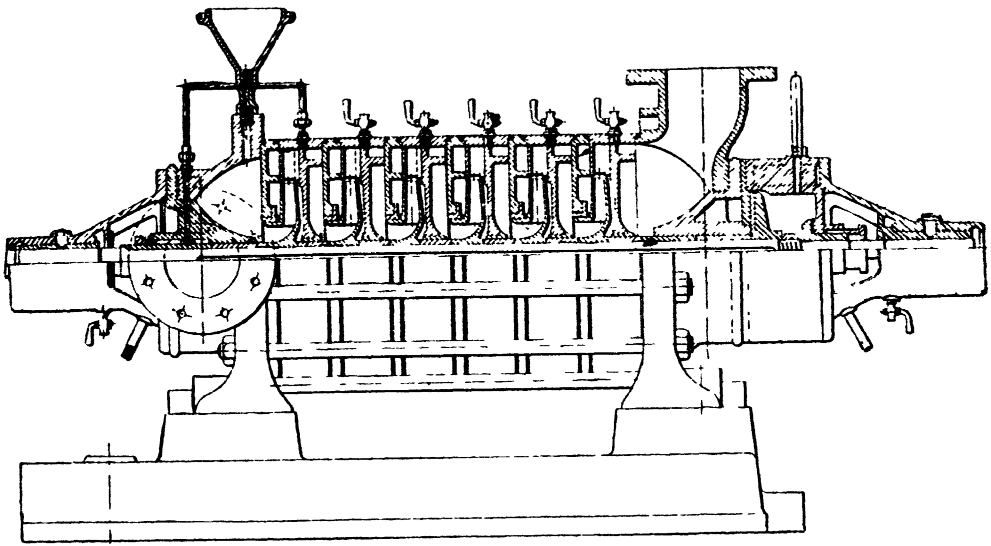


FIG 197 B E P SIX-STAGE TURBINE PUMP

of a six-stage turbine pump made by the British Electric Plant Co., Alloa, to raise 650 gal of water per min., against a head of 700 ft. The motor by which the pump is driven is of 200 h.p., and the set is designed to run at 1460 r.p.m. On referring to the figure it will be seen that water enters the pump at the end next the motor, and in the first cell it has imparted to it enough energy to overcome one-sixth of the total head, then it is discharged through the guide vanes and whirlpool chamber to the eye of the next impeller. As the water passes through the pump it receives in each cell a certain quantity of energy, and when it passes into the rising main enough energy has been given to it to enable it to rise to the head against which the pump works. The suction and discharge branches are carried by the end covers These and the intervening chambers are all registered together by long bolts which run through to the end covers. The latter are provided with feet by which the pump is attached to the sole-plate Cast iron is used in the manufacture of the exterior portions of the pump, but the guide ports and impellers are made of gun metal or phosphor bronze. The shaft is made of mild steel or nickel steel, and if it should be considered necessary the shaft may be protected between stages by sleeves of non-ferrous metal. The bearing housings are of cast-iron, with cast-iron renewable bushes lined with white metal or other approved material. Automatic continuous lubrication is effected by means of oil rings dipping into large oil reservoirs in the housing

Balancing Axial Thrust. The pressure exerted by the impellers of a turbine pump upon the water passing through them is directed towards the suction end of the pump, and if no attempt was made to balance the axial thrust the impellers would become decentralized, and there would be excessive wear between the stationary and rotating parts of the pump. In single-stage, single-entry centrifugal pumps, there is always that lack of balance which is absent in double-entry pumps, and since the head is usually low the axial thrust is balanced by the introduction of a Michell bearing, similar to that shown

in Fig. 198. The following is a description of the system of balancing axial thrust adopted by the Pulsometer Engineering Co., Ltd., London. The chamber *A* in Fig. 199 is supplied with the water under pressure from the last impeller through the clearance *B*, between the spindle and the central bush in the delivery cover The axial thrust towards the suction causes

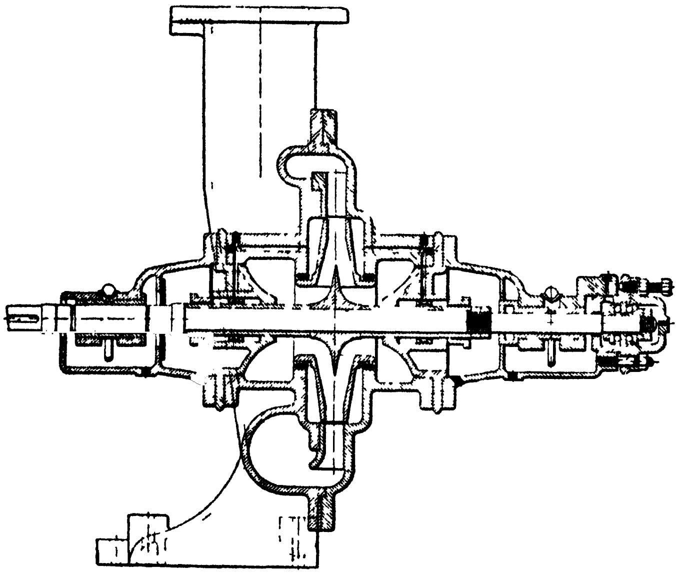


Fig. 198 Centrifugal Pump showing Michell Bearing

the clearance *C* between the balancing disc and its seat to close up, so that more water enters the chamber *A* than leaves it, and the pressure in this chamber therefore increases until the axial force, on the balancing disc towards the delivery cover, balances the axial thrust of the impellers towards the suction cover.

If the axial thrust from the impellers increases, the clearance *C* closes up, and the pressure in the chamber *A* increases until equilibrium is again restored If the axial thrust from the

impellers decreases the clearance C opens, and the pressure in the chamber A is reduced until equilibrium is again restored. The total movement of the disc and spindle is so small that it can hardly be measured. The balancing disc is made so large that there is no danger of its coming into contact with its seat under the most unfavourable conditions of pumping, such as

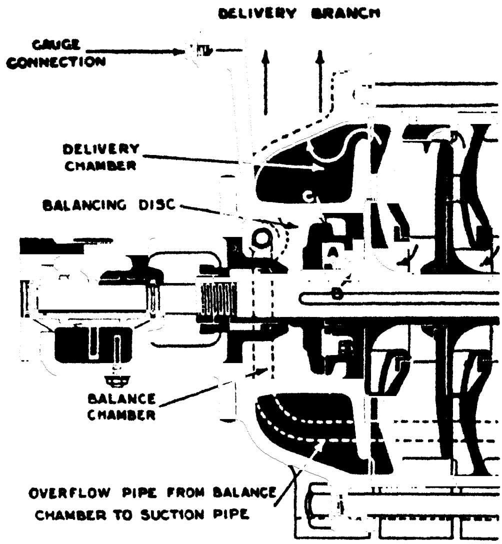


FIG. 199 SHOWING METHOD OF BALANCING AXIAL THRUST

when the pump is running at full speed with no head. As there is no metallic contact there is no wear, except when gritty water is pumped, and when from this cause the wear has become excessive, the disc or its seat, or both, can be replaced in a very short time and at small cost, without dismantling the pump, it being only necessary to remove the bearing. The balancing disc is therefore a perfectly water-cooled thrust bearing working without metallic contact In common with all balancing methods the balance must be paid for by loss of energy in the shape of mechanical friction, or in the shape of

lost water, which in this case will not exceed 1 per cent to 2 per cent of the total water pumped and which is allowed for in the efficiency quoted.

Pulsometer Steam Pump. This is a form of pump in which the valves are the only moving parts, and the principle of its action is precisely the principle introduced by Savery towards the end of the eighteenth century. The water is discharged under direct pressure of the steam, consequently the head against which the pump works is not usually high. Let p be the pressure of the steam above atmospheric pressure in pounds per square inch, h the head in feet, and E the efficiency of the pump (a factor having a value which is dependent on the internal resistance and the amount of condensation of steam that takes place during discharge) then—

Hydrostatic pressure = steam pressure

i.e., $$0{\cdot}434h = pE$$

and $$h = \frac{pE}{0{\cdot}434}$$

Example 82. A Pulsometer pump is supplied with steam at 50 lb per sq. in. (by gauge) and the efficiency is estimated to be 75 per cent. To what height could the pump discharge water ?

Solution. Head $= \dfrac{50 \times 0{\cdot}75}{0{\cdot}434} = \dfrac{37{\cdot}5}{0{\cdot}434} = 86{\cdot}4$ ft. *Ans.*

This example is intended to be representative of the result one would be entitled to expect in practice, for experience shows that a steam pressure of 50 lb. per sq. in. is necessary if the head is about 80 ft. Higher heads would require high pressures.

Fig. 200 is a section of the Pulsometer steam pump, which consists of a single casting called the body, composed of two chambers joined side by side, with tapering necks bent towards each other near the top and surmounted by another casting called the neck, accurately fitted and bolted to it, in which two passages terminate in a common steam chamber, wherein the ball valve is fitted so as to be capable of oscillation between the seats formed in the junction. Downwards, the chambers

are connected with the suction passage wherein the inlet or suction valves are arranged. A discharge chamber, common to both chambers, and leading to the discharge pipe, is also

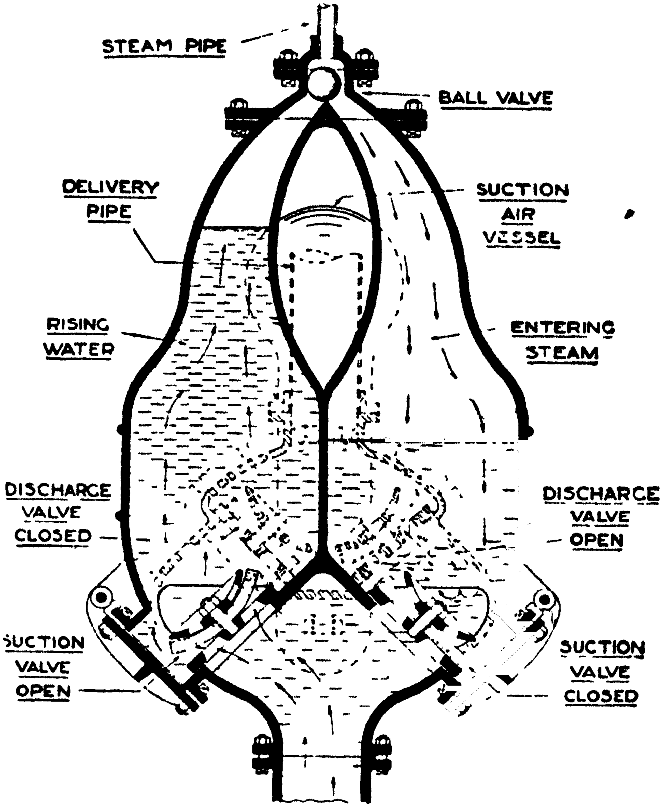


FIG. 200 PULSOMETER PUMP

provided, and this also contains one or two discharge valves, according to the purpose to be fulfilled by the pump. The air chamber communicates with the suction The suction and discharge chambers are closed by hinged covers shown near the suction valves, accurately fitted to the outlets by planed

joints, and readily removed when access to the valves is required; in larger sizes handholes are provided in these covers. The amount of opening of the suction valves is controlled by guards.

Action of Pulsometer Pump. When the pump has been primed, steam is admitted to the steam pipe, and passing down that side of the steam neck which is left open to it by the position of the ball valve, presses upon the small surface of the water in the chamber which is exposed to it, depressing it without agitation, and consequently with but little condensation, and driving it through the discharge opening and valve into the discharge pipe. When the water reaches the orifice leading to the discharge pipe, the steam blows through amongst the turbulent water and condensation at once takes place, with the result that a vacuum is formed in the newly-evacuated chamber, and the ball valve rolls over and closes the steam inlet to that chamber. The steam passes into the other chamber now, and while that is being evacuated the first is being filled by the pressure of the atmosphere on the free surface of the water in the sump Each chamber is filled and evacuated in the same way, and a continuous discharge of water is maintained by the alternating discharge of the water from the chamber. The Pulsometer pump has in the past been found to be exceedingly useful in raising gritty water from the bottom of the sinking shafts, and, although it is not economical in steam consumption, it has been used with good results in dealing with large quantities of water from sinking shafts. The pumps installed at the sinking of Maypole Colliery, Wigan, were capable of dealing with 80,000 gal. of water per hour. The pump is simple in construction and consumes its own exhaust steam.

Pohle Air-lift Pump. This is a pump in which water is raised economically without the use of solid pistons or valves. Fig. 201 is a section showing the relative positions of the pipe *A* conveying compressed air to the bottom of the eduction pipe, the eduction pipe *P* itself, and the shaft or well in which the pump is placed. As will be readily understood, the level

of the water within the eduction pipe and outside of it is the same before the supply of compressed air is turned on, but when compressed air is supplied to the lower end of the eduction pipe water is discharged from the upper end of the pipe. The motive force operating the pump is the buoyancy of the bubbles of air ascending the eduction pipe. Consider a bubble of volume O rising in the pipe with a relative velocity v_1. If a be the cross-sectional area of the eduction pipe in square feet the volume of water which will pass from above the bubble to the under side of it will be av_1 cub. ft. per sec. In passing to the under side of the bubble the water would acquire some absolute velocity which we may call v_2. It is thus seen that the kinetic energy given to the water passing downward past the bubble is equal to the work done by the bubble in ascending the pipe, hence $O\delta v_1 = \delta a v_1 \times \frac{v_2^2}{2g}$ where δ is the density of the water in pounds per cubic foot. The expression takes the simpler form $\frac{O}{a} = \frac{v_2^2}{2g}$, and this gives the head h at the top of the pipe which is necessary to produce the velocity v_2, therefore $h = \frac{O}{a}$. This simpler form of the general expression shows that the value of h is dependent on the volume of air supplied to the pump per unit of time, and varies inversely

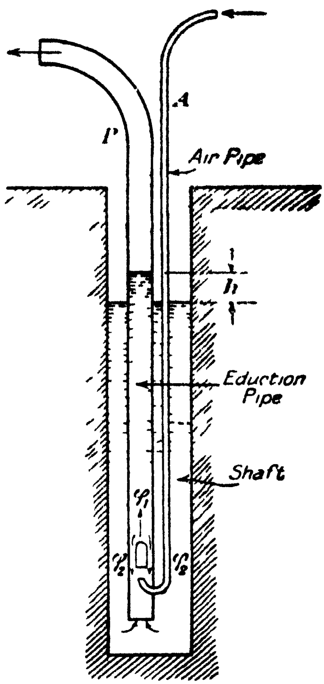


FIG. 201. POHLE AIR-LIFT PUMP

as the area of the eduction pipe. The velocity of slip v_2 is obviously proportional to the square root of the volume O of the bubble, therefore it is desirable that the volume of the bubbles ascending the pipe should be small. That is why air is introduced to the Frizell air-lift pump through a series of small openings at the base of the eduction pipe. It is only in this particular that the Pohlé and Frizell systems differ. The air-lift pump is not efficient, even when the most favourable percentage length of the eduction pipe is submerged, but we may regard it as a serviceable system of raising water from shafts and wells in special circumstances or in cases of emergency.

Draining Flooded Dip Workings. The dip workings of a mine may become flooded with water due to one or other of the following causes, viz.—

1. Failure of pumps and delay in effecting repairs.
2. Compulsory cessation of pumping operations.
3. Sudden inrush of water from old workings in the same seam, or from abandoned workings in another seam at a higher level.
4. Irruption of water from the surface arising from subsidence.

Having regard to the particular circumstances in which recovery work is done, it is quite apparent that the pumps which it is proposed to install should be portable, that is, they should be light and capable of being mounted on a trolley or truck. If the road is high the pump may be mounted on a trolley in the horizontal position, the back end of the trolley being made up by a deep pedestal on the back axle. The arrangement suggested is quite a usual one when a turbine pump is mounted on a trolley with the pump and motor shaft in the direction of the dip, but if the gradient is high the arrangement shown in Fig. 202 may be adopted with advantage.

The figure shows a Sulzer turbine pump mounted upon a frame of rolled-steel joists and arranged to run on the ordinary tub track. Allowance is made for the inclined position and

the gravitational axial thrust by specially-designed bearings In similar circumstances the British Electric Plant Co., of Alloa, take up gravitational axial thrust by a ball-bearing. The movement of the pump is effected by a rope which passes round the drum of a winch or crab farther up the incline, and as the water recedes from the pump the latter is lowered so that the strainer is always under the surface of the water.

FIG. 202 SULZER PUMP

Unless the motor is specially designed, it is inadvisable to allow it to become wet, for the insulation might be affected by the dampness and break down, but if the motor is contained in a specially-designed casing the whole pump may be totally submerged without risk of accident of any kind. Gwynnes Engineering Co., Ltd., are manufacturers of the submersible turbine pumps. Fig. 203 shows a submersible pump which was used at the recovery of the dip workings of Cannop Colliery, Forest of Dean, after the dispute of 1921. It is seen that the pump is placed across the supporting truck, and consequently there is no gravitational axial thrust on the pump shaft The suction pipe was a flexible one which, with the strainer

was supported on another truck connected to that carrying the pump itself by two iron rods. By this arrangement it was possible to keep the suction pipe extended, for as the pump was lowered so was the truck carrying the flexible pipe. It is not always possible to have to hand everything required for the unwatering of a mine, for a case of emergency is one in which one makes immediate use of every available piece of machinery that can be pressed into service. It is on that account that one may find a steam pump side by side with

FIG. 203 GWYNNE'S SUBMERSIBLE PUMP AT CANNOP COLLIERY

electric pumps, or pumps driven by compressed air ; and one may find it necessary to place a turbine pump, or a reciprocating one, on the floor instead of having it mounted on a frame carried on rollers.

Sinking Pumps. A quarter of a century ago there were still to be found in pits which were being sunk those " travelling sets " of bucket and plunger pumps that will be remembered for their enormous weight and small capacity. But the day of the small, high-capacity pump has arrived, with great advantage to those who have the responsibility of sinking pits through heavily-watered strata. With the advent of the cementation and freezing methods of stopping the influx of water to shafts, there is not the same need for pumping such large quantities of water as used to be dealt with, but even if

that need still existed, it would be found that a great advance had been made in the design of sinking pumps. It is common experience that the occurrence of feeders of water is associated with the permeability of the rocks passed through by shafts. Shales may be comparatively dry, but the interstratified beds of sandstone may be fissured and give off much water. It is because of the zonal occurrence of water in shafts that pumping stations are, as a rule, made in the first impervious bed found after sinking through the water-bearing bed. Travelling pumps are used to raise the water from the bottom of the shaft to the surface, or to the lodge last made in the shaft. Where there is more than one intermediate lodge, the water may be raised from the shaft-bottom to the first; then from one lodge to the other, and so on till the surface is reached. In choosing the position of permanent pumping stations due consideration should be given (1) to the centralization of plant, and (2) to the efficiency of centralized plant as against that of plant placed at the points of influx of water to the mine.

One point is always worthy of note in such a consideration, and that is that water should not be allowed to fall down the shaft unless it be conveyed in pipes leading to the suction side of a pump which can take advantage of the hydrostatic head. The turbine pump is most suitable in this respect, but in consideration of the gritty matter in the water, or the possibility of the pump losing its water, it might possible be better to install a plunger pump in the shaft-bottom with turbine pumps to deal with the clean water above.

Evans's "Cornish" Sinking Pump. Fig. 204 is a sectional front elevation of the "Griff Pattern" Cornish steam pump made by Joseph Evans & Sons, Wolverhampton. The pump is designed to pump against a head of 300 ft., the suspension being made by means of chains, rods, or ropes, to enable it to be slung within suction distance of the water It is fitted with a removable liner which can be changed after wear occasioned by pumping gritty water. The pump has a double-acting piston, and it is fitted with two suction valves. The body of the pump is of special design; it has a lined working-barrel

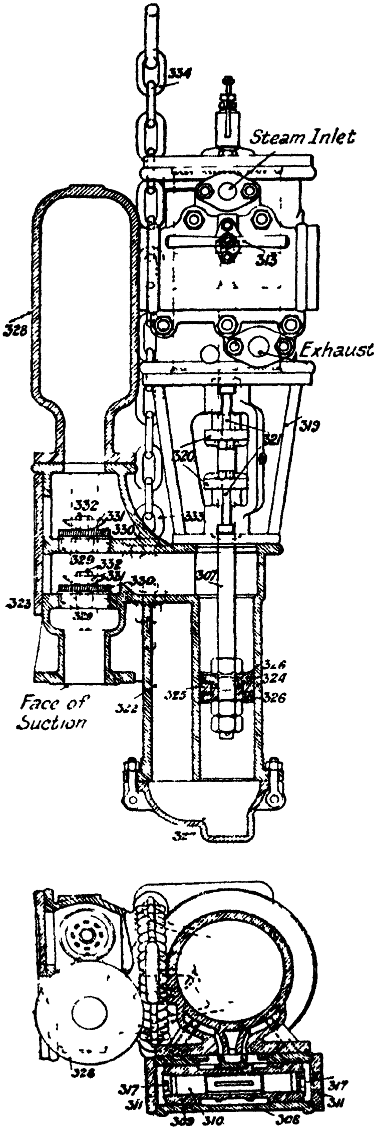


FIG. 204. EVANS' "CORNISH" PUMP

which is connected at one end by a bonnet (327) and eyebolts to another compartment in the same casting, and the upper end of the working-barrel proper is connected to one side of the four-doored valve-chest, while the upper end of the corresponding compartment is connected to the other side of the valve-chest.

Considering the pump to be filled with water, the action may be described as follows: When the upward stroke is made, water is discharged from the working-barrel through the discharge valve, seen in the figure, into the rising main which is set on the top of the valve-chest. Meanwhile water has passed through the suction valve, which is not seen in the figure, down through the vertical compartment and bonnet to the underside of the piston. During the downward stroke the water under the piston is discharged back through the bonnet and vertical compartment through the delivery valve, not seen in the figure, to the rising main, and while that has been taking place water has been passing through the suction valve, seen in the figure, to the upper side of the piston. The respective positions of the air-vessel, steam inlet, and exhaust pipe are shown in the figure. This pump has had a most extensive application to pumping in sinking shafts, and it is made in sizes varying from 2 to 16 in. in diameter.

Turbine Sinking Pump. Desirable features of sinking pumps are that they should have the greatest possible capacity for dealing with water, combined with compactness of design, and that they should be easily and quickly transferred from one position to another. No pump combines those features so well as the electrically driven turbine pump. Fig. 205 shows the general arrangement of the pump, suction and discharge pipes, platform, and ladderway, of the well-known "Plurovane" turbine pump made by Messrs. Mather & Platt, Ltd. The characteristics of this pump show that while the maximum efficiency of 76 per cent is attained when the pump is raising 600 gal. of water per min. against a head of 690 ft., the efficiency is 72 per cent when the pump is discharging 800 gal. of water per min. against a head of 580 ft. Because sinking

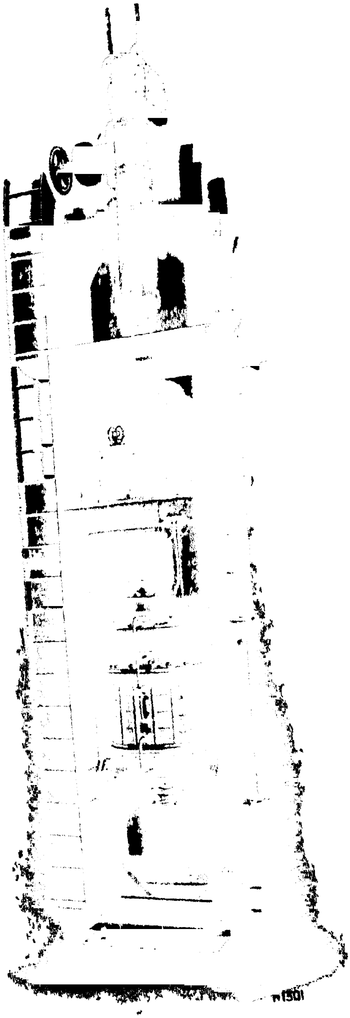


FIG. 205 MATHER & PLATT'S PLUROVANE SINKING PUMP

pumps may have to deal with gritty water it is important that the rotary portion of the pump and the chamber liners should be made of some material which offers a high resistance to abrasion. Messrs. Mather & Platt make the working parts of their turbine pumps, both rotary and stationary, of a special

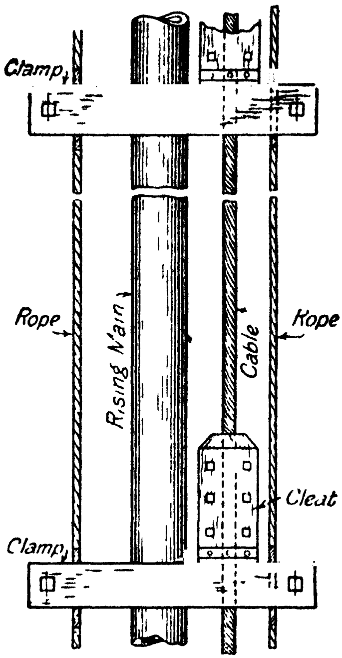


FIG. 206 SUSPENSION OF SINKING PUMP

zincless bronze which has a high tensile strength and great power to resist abrasion They were the pioneers of the development of turbine pumps for all classes of hydraulic work, and still occupy a foremost position among makers of high-class pumping machinery. At the time of the recovery operations following the Redding disaster, much was heard of the famous Kinglassie pump, a particular pump which took its name from the colliery at which it was originally installed.

The pump was in fact a B.E.P. sinking pump, manufactured by the British Electric Plant Co., Ltd. The pump is suspended in precisely the same manner as the Plurovane pump, and because it occupies a vertical position the motor is provided with ball-bearings to carry the armature and reduce friction due to gravitational thrust. The motor is ventilated and drives the pump through a flexible coupling, the complete unit being mounted in a girder framework for lowering down the shaft. Platforms are provided for access to pump, motor, and valves. The pump first installed at Kinglassie Colliery with accessory equipment weighed about 15 tons, and was swung from a crab fixed on the surface. Its capacity was 1000 gals. of water per min. when working against the normal head, but at lower heads it discharged 1300 gals. per min. As the pump descends the shaft the electric cable conveying the current is unwound from the reel on the surface, and pipes are added to the rising main as required. Glands are attached to the supporting rope to embrace the rising main and the power cable, and these form suitable supports for the cleats used to carry the weight of the electric cable. Fig. 206 shows the mode of attaching the wooden glands to the hoisting rope.

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EXERCISE QUESTIONS

1 A three-throw pump has single-acting rams $8\frac{1}{2}$ in in diameter 10 in stroke At about what speed should the crankshaft revolve to handle 250 gal per min of water and what should be about the brake horse power of an electric motor to drive the pump if the total head from all causes is 400 ft ?

(*2nd Class Exam* May, 1931)

2 Describe a pump suitable for draining the face of an incline being driven to the deep the power being compressed air The water may amount roughly to 50 gal per min Deal with both the water end and the compressed air end of the pump

(*2nd Class Exam* Nov , 1931)

3 A centrifugal (or turbine) pump direct coupled to an electric motor is at work underground Give a list of the auxiliary gear and instruments that may be installed for starting and controlling the motor and pump and for showing the performance of the plant (*2nd Class Exam* , May, 1932)

4 Compare the merits of a pump driven by compressed air and one driven by electric motor for keeping the advancing face of an incline free from water which comes in at the face

Briefly describe the pump that you would install

(*2nd Class Exam* Nov 1932)

5 Draw a simple diagram to illustrate the action of a ram in a cylinder with the necessary valves to form a single acting pump for raising water

A single acting ram or plunger is 6 in in diameter and works under a total head (from all causes) of 300 ft It makes 30 complete reciprocations or double strokes per minute and raises 30 gal per min

Calculate the stroke and horse power (*a*) if there is no slip, and (*b*) if the slip is 20 per cent of the volume swept by the ram

(*2nd Class Exam* , May, 1933)

6 Make a sketch of a double acting pump having a single ram outside packed (*2nd Class Exam* May, 1934)

7 Describe a pump suitable for use with compressed air and for raising water at the rate of about 50 gal per min to a total head of about 200 ft with an inlet air pressure of 60 lb per sq. in.

Deal with both the compressed air and water ends. What special provisions would you make to deal with dirty water?

(*2nd Class Exam.*, Nov., 1934.)

8. Compare a motor-driven ram pump with a motor-driven centrifugal (or turbine) pump, and describe underground conditions for which each type of pump is the more suitable.

(*2nd Class Exam.*, May, 1935.)

9. The ram of a direct double-acting pump is 5 in. in diameter, the stroke being 12 in., the rod common to both ram and piston being 2 in. in diameter.

The barrel or ram case is in two portions, with outside packing glands between. Draw a simple diagram of the ram case and ram with rod.

Calculate the gallons of water delivered by a double stroke of the ram (once to and fro), assuming there is no slip.

(*2nd Class Exam.*, Nov., 1935.)

10. An incline is being driven, dipping 1 in 5. The measures are wet with water dripping from the roof. The rate of incoming water is 40 gal. per min. Electric power and compressed air are available. Describe a portable pump plant for keeping the incline drained, the head being limited to 100 ft. Give reasons for your choice. (*2nd Class Exam.*, May, 1936.)

11. A three-throw ram pump has its ram cases, delivery-valve boxes, and suction-valve boxes all separate. Make a hand sketch, showing diagrammatically a section through one ram case and its delivery- and suction-valve boxes, indicating the ram and the valves and seats. (*2nd Class Exam.*, Nov., 1936.)

12. An incline is being driven down at 1 in 5. Water at the rate of 40 gal. per min. accumulates at the face. Describe a complete electric pumping plant suitable for keeping the incline dry for the workers and for raising the water to a total head of 100 ft. (Do not deal with the delivery pipes or electric cable.)

(*2nd Class Exam.*, May, 1937.)

13. Describe the Worthington type of pump and how it works.

(*2nd Class Exam.*, Nov., 1937.)

14. Describe a pump suitable for use in an advancing incline and for driving by compressed air. The water is likely to be dirty and to carry grit. Would you use a piston or a ram in the water cylinder? Give the reason for your answer.

What type of valve and seat would you adopt for the water end?

(*2nd Class Exam.*, May, 1938.)

15. Water collects in a swamp or low place in colliery workings and after a time impedes working. The feeder is about 20 gal. per min. Describe a low-head pump outfit suitable for keeping the

swamp drained Either electricity or compressed air is available.
(*2nd Class Exam*, Nov, 1938)

16 Describe a centrifugal pump with a single impeller arranged for coupling direct to an electric motor (not to be described) What valves are useful or essential in working and controlling a centrifugal pump? (*2nd Class Exam*, May, 1939)

17 Describe a pumping plant for a sinking shaft to include a centrifugal (or turbine) pump coupled direct to an electric motor, and the accessories of the pump, which is to be arranged to follow the sinking as it proceeds (*1st Class Exam* May 1931)

18 A centrifugal (or turbine) pump has 5 impellers in series, 13 in in diameter running at 1440 r p m The delivery branch is 7-in bore and the suction branch is 8 in bore For what rate of delivery of water and head would this pump be suitable?
(*1st Class Exam*, Nov, 1931)

19 The feeder of water to be pumped up a shaft 1000 ft deep is 500 gal per min in winter and 250 gal per min in summer Electric power is to be used Reliability is important Discuss the types of pump that might be used and say which you would adopt and in what numbers and capacities Give reasons for your choice (*1st Class Exam*, May, 1932)

20 In connection with a centrifugal (or turbine) pump whose economical duty is 1000 gal per min 700 ft high at 750 r p m, coupled direct to an electric motor

(*a*) If the speed is increased to 1000 r p m what is then the economical head and quantity per minute?

(*b*) If the motor were overloaded at the economical duty (1000 gal per min 700 ft high) how could you reduce the load whilst maintaining the speed?

(*1st Class Exam* May 1932)

21 Describe a reciprocating steam pump suitable for use in a sinking shaft, and state the provisions that may be made for better dealing with gritty water

What size of pump would you choose for raising 200 gal per min to a height of 300 ft with steam at a pressure of 60 lb per sq in at the stop valve? (*1st Class Exam*, Nov, 1932)

22 Set out the information that should be given to a manufacturer to enable him to offer a centrifugal (or turbine) pump coupled direct to an electric motor for placing at the bottom of a shaft to raise water up the shaft Deal with both the pump and the motor, but not with the switchgear,
(*1st Class Exam*, Nov, 1933.)

23. In connection with multi-stage centrifugal or turbine pumps—

(*a*) What is the highest suction head that you would arrange for ordinary cold water?

(*b*) Describe the operation of starting the pump and also of stopping it.

(*c*) What are the points to watch in keeping the pump running well?

(*d*) What parts of the pump are the most liable to wear?

(*e*) If the driving electric motor is overloaded, how can the load on the pump be lessened at constant speed?

(*1st Class Exam.*, May, 1934.)

24. Describe the action of a centrifugal (or turbine) multi-stage pump.

Draw typical curves connecting the head, rate of flow, power, and efficiency for such a pump. (*1st Class Exam.*, Nov., 1934.)

25. In connection with multi-stage centrifugal (or turbine) pumps—

What kind of packing is used to prevent the leakage of air into, or of water out of, the pump where the shaft passes through the casing?

What is a lantern gland, and how does it function?

At what places inside the pump may leakage of water occur back towards the suction end?

What steps can be taken to make a centrifugal pump more suitable for handling gritty or acid water?

(*1st Class Exam.*, May, 1935.)

26. An incline is being driven down in a seam dipping 1 in 6 and is now 1800 ft. long. Water at the rate of 200 gal. per min. flows into the incline at a point 1200 ft. from the top, and below this point the inflow of water is 60 gal. per min.

Describe the equipment of pumps and pipes that you would install for raising the water to the top of the incline and for keeping the face clear for the work of advancing the incline. The type of power is open to choice. (*1st Class Exam.*, May, 1935.)

27. Describe an electrically driven centrifugal (or turbine) pumping plant suitable for a sinking shaft and for a duty of about 500 gal. per min. to an ultimate height of 1000 ft.

The electric power is three-phase, 50 cycles, 440 volts between phases. (*1st Class Exam.*, Nov., 1935.)

28. How may thrust be taken up on the spindle of a centrifugal multi-stage pump or of a steam turbine?

Describe one apparatus for this purpose.

(*1st Class Exam.*, May, 1936.)

29 Give a careful description of a multi-stage centrifugal, or turbine, pump—say for 300 gal per min, 500 ft head Ignore the driving motor

A centrifugal pump is able to lower the water in an incline faster when the suction pipe is short than when it is long, due to the water surface being farther away Explain this

(*1st Class Exam*, May, 1936)

30 A centrifugal (or turbine) pump has a duty of 750 gal per min to a head from all causes equivalent to 500 ft of water It is placed near the sump State the maximum suction head that you would allow for also the diameter of suction and delivery pipes that you would use

Also describe the joint that you would adopt for the delivery pipes and give a list of the valves in the pipe ranges external to the pump (*1st Class Exam* Nov, 1936)

31 Describe the action of a centrifugal (or turbine) multi stage pump in raising in water What are the various common arrangements of casing of these pumps? State the merits of each design

(*1st Class Exam* May, 1937)

32 What are the materials commonly used for the casing impellers guide vanes shafts sleeves bushes and bearings of multi-stage centrifugal (or turbine) pumps?

If the water is acid or corrosive what changes may be made in the materials used to cope with it? (*1st Class Exam* Nov 1937)

33 A shaft 16 ft in diameter is to be sunk to a depth of 600 ft The inflow of water is expected to be up to 900 gal per min Give in outline a specification of the complete pumping plant that you would install in and about the shaft for raising the water and to keep the bottom fit for the sinkers to work in

Assume that any kind of power is available

(*1st Class Exam* Nov, 1937)

34 A multi stage centrifugal (or turbine) pump has 6 impellers 10 in in diameter with a width of opening at the rim of 0 65 in The suction branch is 5 in bore The delivery branch is 4 in bore The pump runs at 1440 r p m What are approximately the best conditions of head and of rate of flow of water?

If such a pump fails to deliver water (through a fault not connected with the driving motor) where would you look for possible causes? (*1st Class Exam* May 1938)

35 Discuss the types of pump available for keeping dry the advancing face of an incline Assume that either compressed air or electricity is obtainable Deal with the matter from the points of view of convenience, reliability wear of parts, and cost of running The feeder of water may amount to 60 gal per min

(*1st Class Exam*, Nov, 1938)

36. The water to be pumped at a colliery varies between 100 gal. per min. for five summer months, 250 gal. per min. for six months, and 320 gal. per min. for one winter month. The head from all causes is 300 ft. Electric power of three-phase type, 400 volts, 50 cycles, is available.

Give a specification in outline of the pumping plant that you would install, bearing in mind that it is desirable to keep down the demand for power. Do not deal with switchgear.

(1st *Class Exam.*, May, 1939.)

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